Space Project Mission Operations Control Architecture (SuperMOCA)

SuperMOCA SYSTEM CONCEPT

Volume 3

Operations Concepts

January 1999

ORIENTATION

The goal of the **S**pace **Pr**oject **M**ission **O**perations **C**ontrol **A**rchitecture ("SuperMOCA") is to create a set of implementation-independent open specifications for the standardized monitor and control of space mission systems. Monitoring is the observation of the performance of the activities of these systems. Controlling is the direction of the activities performed by these systems. Overall, monitor and control is the function that orchestrates the activities of the components of each of the systems so as to make the mission work. Space mission systems include:

spacecraft and launch vehicles that are in flight, and;
their supporting ground infrastructure, including launch pad facilities and ground terminals used for tracking and data acquisition.

The SuperMOCA system concept documents consist of the following:

SuperMOCA System Concept, Volume 1: Rationale and Overview
SuperMOCA System Concept, Volume 2: Architecture
SuperMOCA System Concept, Volume 3: Operations Concepts
SuperMOCA System Concept, Annex 1: Control Interface Specification
SuperMOCA System Concept, Annex 2: Space Messaging Service (SMS) Service Specification
SuperMOCA System Concept, Annex 3: Communications Architecture
SuperMOCA System Concept, Ancillary Document 1: Ground Terminal Reference Model
SuperMOCA System Concept, Ancillary Document 2: Operations Center to Ground Terminal Scenarios
SuperMOCA System Concept, Ancillary Document 3: Operations Center to Ground Terminal – Comparison of Open Protocols

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1. INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to provide an overview of the operations concept for the proposed Space Project Mission Operations Control Architecture (SuperMOCA). This document's scope does not go beyond providing several operational scenarios with various levels of spacecraft autonomy to show how space missions could perform the device monitor and control function as seen from the SuperMOCA perspective. Users of SuperMOCA include the flight operations team, the science investigation teams, and infrastructure resources such as spacecraft control centers and the Deep Space Network (DSN).

Hopefully, this document will present to the reader several operational scenarios on how SuperMOCA can provide guidance for space missions in the implementation of lower cost, and lower risk mission operations. Engineering guidance discussed is presented through a description of how SuperMOCA could be implemented under a wide variety of spacecraft control scenarios: from tight control of the spacecraft by the ground to a high degree of spacecraft autonomy. These scenarios form baselines for low cost approaches for operating spacecraft. The concepts and approaches captured in this document have been designed and developed from NASA missions and are based upon the following precepts, as a minimum:

- Maximal reuse of functions and systems among missions
- Use of open systems concepts and standards for device monitor and control
- Use of commercially available technologies as embodied in off-the-shelf hardware and software

It is important to emphasize that the information contained in this document represents an initial concept of operations with the goal of reducing costs in the monitor and control of space mission devices (both on board and on the ground). This information is expected to be refined and/or further developed as experience is gained during the development of SuperMOCA coupled with the use of SuperMOCA prototypes in various testbeds. It is recognized that many missions may not be able to adopt all the concepts promoted by SuperMOCA due to their specific scientific investigations and spacecraft design. SuperMOCA is intended to serve as a foundation for missions by providing designed-in flexibility. In cases where specific, or special purpose resources and services are required, SuperMOCA is designed to accommodate these resources and to integrate them into the SuperMOCA framework.

Refer to the following document for further information regarding SuperMOCA from a higher level perspective: System Concept: Volume 0, SuperMOCA Summary.

1.1.1 REFERENCE DOCUMENTS

- SuperMOCA System Concept Volume 1: Rationale and Overview Document, January 1999.
- SuperMOCA System Concept Volume 2: Architecture, January 1999.
- Concept of Operations, Volume 1, MOCA Definition Document, The Mission Operations Control Architecture, SAIC, April 24, 1995.
- Architectural Framework, Volume 2, MOCA Definition Document, The Mission Operations Control Architecture, SAIC, April 24, 1995.
- Renaissance Study of Spacecraft Integration and Test Systems, Mission Operations and Data Systems Directorate (Code 500), Goddard Space Flight Center, 504-IT-01, February 1996.
- Development of an Interoperability Architecture for Unmanned Aerial Vehicles, SRI International, V2.0, Jan 16, 1995.

1.1.2 DEFINITIONS

Directive: A control instruction generated by a user.
Command: A control instruction generated by a device.
Message: A directive, command, or monitor data encapsulated within a data unit by a messaging system.

2. CONTEXT VIEW OF SUPERMOCA

2.1 SUPERMOCA OPERATION PHASES AND HIGH LEVEL ACTIVITIES

SuperMOCA provides support for a mission throughout its life cycle. Figure 2-1 illustrates the operational phases of a mission beginning with the development, integration and test phases through mission operations. The figure also identifies major activities performed during each phase. The figure does not include all possible mission phases nor all possible activities. Rather, it identifies phases and activities that influence the mission common to all spacecraft. The illustrated phases and activities can be adapted to any mission and additional phases and activities can be added.

A mission to be developed and operated within the SuperMOCA context begins on the ground during the design, development, and testing phase. The mission uses the interfaces, standards, and technologies promoted by SuperMOCA as an input to the spacecraft and ground system design. Similarly, the instrument(s)/payload(s) use SuperMOCA as an input to their design. Ground system personnel monitor and evaluate the spacecraft and instrument/payload progress to determine any special and unique interfaces to be added to SuperMOCA or for standards that require modification. While both space resources and ground system are being implemented, SuperMOCA is used for end-to-end testing and simulations to demonstrate system compatibility, reliable data transport, and reliable control/monitor capabilities. These tests may be done using the system in various integration and test modes and models. The tests may be done with prototypes, emulators, flight hardware/software, and the full scale integrated system. There are advantages to be taken during the system integration phase of a SuperMOCA compliant mission. Since device monitor and control interfaces are standardized and messaging system specifications provide a wide range of device communication capabilities, projects are in a position to integrate their systems in a more flexible manner than before. Tests also may be performed while the system or component is in the lab, I&T facility, or environmental chambers.

The pre-launch phase occurs at the launch site. This phase consists of final integration and test checks of the spacecraft and launch vehicle coupled with the spacecraft preparation for launch. This preparation includes the arming/disarming of pyrotechnics, battery charging, and attitude/propulsion tank fueling. During this phase, SuperMOCA forms the foundation for supporting pre-launch activities in a standard way for the final end-to-end testing and simulations. This phase ends with the completion of Launch Readiness.

The launch phase begins with the launch countdown and ends with spacecraft separation from the launch vehicle. During this phase, there is not much activity with the spacecraft. However, in some implementations, the spacecraft is in a minimal operating mode and provides telemetry data. Projects monitor the data for evaluation of the spacecraft's health and safety. In some cases, for example Shuttle launches, SuperMOCA provides, via standard messaging services, command capability to the spacecraft through the Shuttle system.

When launch is complete, the orbital injection phase begins and lasts until the spacecraft is inserted into the proper orbit/trajectory. During this time, the spacecraft starts activating its systems using pre-planned and stored sequences. Initial deployments, for example antennae and solar arrays, occur. Initial attitude acquisition begins to remove any “tip-off”, large torque about the axes, or tumbling effects, and to place the spacecraft in the proper attitude, for example in a sun bathing mode - one where the solar arrays face the sun to re-charge the batteries or to orient the communication antennae. The spacecraft operates in an autonomous mode with telemetry data being transmitted. The project, through telemetry, monitors spacecraft health and well-being and determines that initial deployments have happened.

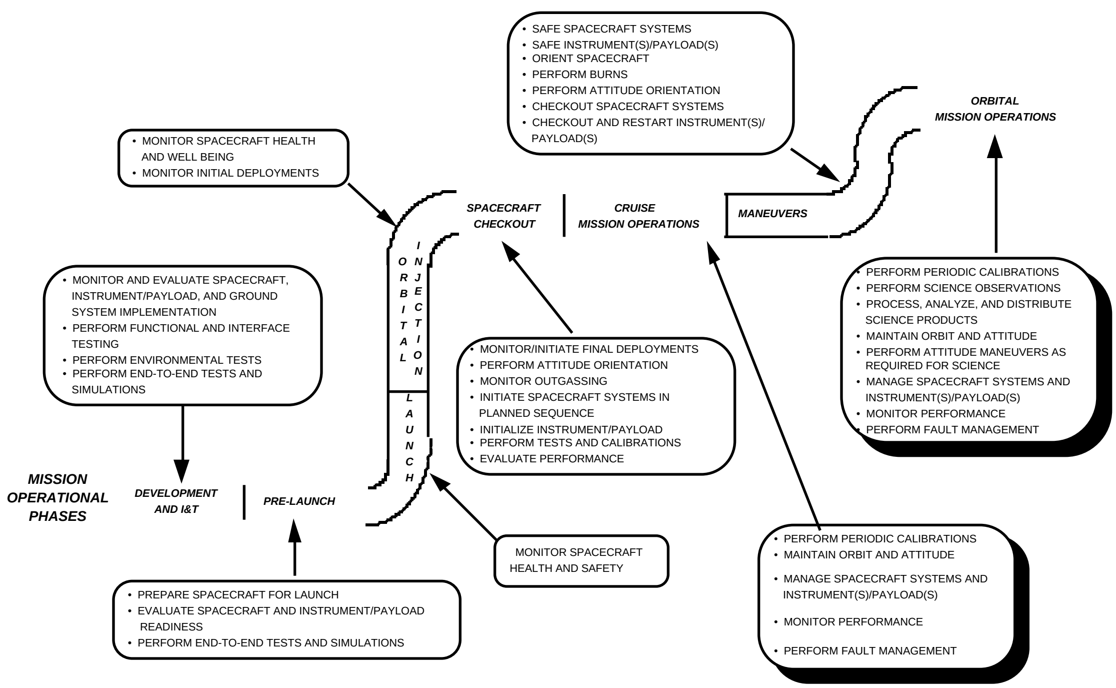

Figure 2-1 Mission Phases and High Level Operational Activities

With the spacecraft injected into orbit, the on-orbit checkout phase begins. This phase provides for the initial and complete checkout of all spacecraft systems and instrument(s)/payload(s), final attitude orientation maneuvers, final deployments, and calibration. During this phase and prior to completion of the phase, the project can initiate checks to verify its SuperMOCA interfaces and capabilities. These include commanding, monitoring health and safety, collecting and transmitting data using standard messaging system services. With all systems, services, and capabilities checked out, validated, and calibrated the instrument(s)/payload(s) are declared operationally ready to begin the science mission (or for interplanetary spacecraft, the cruise portion of the mission).

The on-orbit mission operations phase performs scientific observations as required and directed by the designated science investigators. The activities of this phase are science related - to orient the spacecraft as needed for observations, to collect and transmit science data, to periodically calibrate the instrument(s)/payload(s), to maintain spacecraft health and safety, and to process and distribute the science data. SuperMOCA supports these activities by providing a standard linkage between the science investigators and their instruments. In addition to servicing the science investigators, SuperMOCA supports management of the spacecraft resources needed for overall spacecraft health and safety and supporting the science mission. Spacecraft activities include attitude orientation, monitoring performance, managing faults, and the movement of data among the mission elements.

Some science missions include transitions in orbit or attitude that can affect overall spacecraft health and safety. The maneuver phase is used to interrupt the normal on-orbit mission operations phase to “move” the spacecraft in a safe and reliable manner. This phase provides the safing of all spacecraft systems prior to a maneuver. The safing includes locking or storing deployables, placing shields over spacecraft apertures, and placing the spacecraft in a low power mode. The spacecraft’s propulsion system and/or attitude maneuvers are then initiated. When the spacecraft achieves its desired orbit and/or attitude, the spacecraft is checked out for health. Then, the spacecraft and its instrument(s)/payload(s) are transitioned to nominal operations. This transition includes removing shields and unlocking deployables.

The next sections will describe how SuperMOCA is applied to the major phases in a typical mission life cycle and how SuperMOCA standard interfaces, information architecture, and technologies work in a space mission. The file cycle phases that will be looked at will be: Integration and Test, Launch operations, and Orbital operations (including orbital/trajectory maneuvers).

3. INTEGRATION AND TEST (I&T) SCENARIO

3.1 INTRODUCTION

This section presents an operational scenario for the integration and test phase of a mission from the perspective of the space system user (e.g., scientist, engineering team member). The components that are available to the user include the I&T system (test workstations, ground support equipment), ground terminal simulators, and the spacecraft (see Figure 3-1). This scenario examines how SuperMOCA standard interfaces could improve spacecraft I&T.

3.2 MISSION PHASE VIEWPOINT

A mission begins on the ground during the design, development, integration and testing phases. Spacecraft designers use SuperMOCA specifications as an input to the spacecraft design. In the current SuperMOCA paradigm, little of the spacecraft is built in-house, as off-the-shelf devices are procured to meet mission requirements. These devices are delivered by the vendors with a SuperMOCA compliant standard logical front-end that is visible to the rest of the spacecraft and ground system. This logical front end will be designated a virtual device.

“Generic” Spacecraft System Integration and Test Diagram

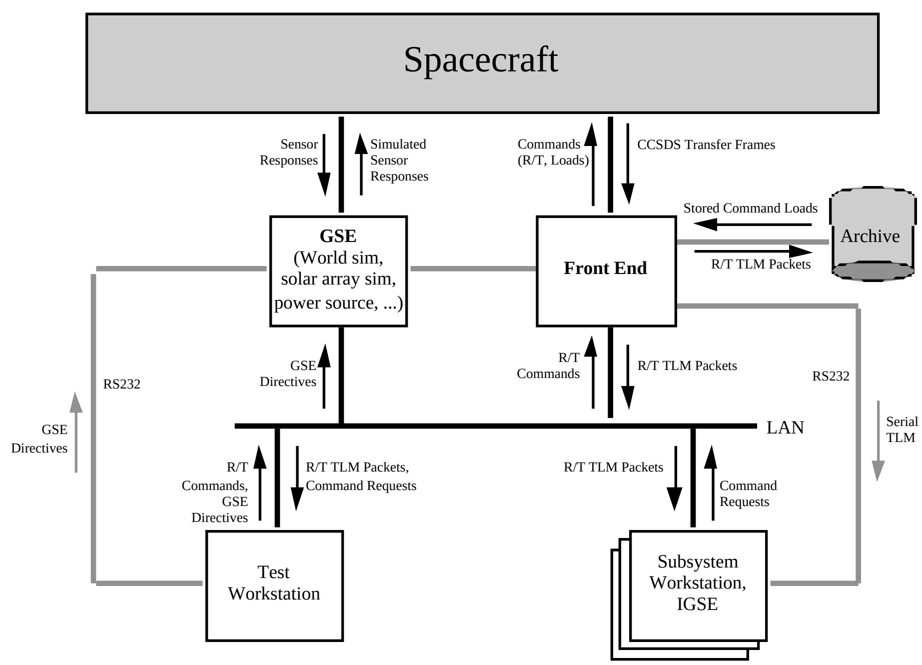

Figure 3-1 Spacecraft Integration and Test System

As stated before in the SuperMOCA Architecture Document, a virtual device provides the space mission with a standard way to communicate with the real physical device, freeing the project from having to build a customized control interface for each device (or class of devices). A virtual device in other words, standardizes the external interfaces of the real physical device in such a way that regardless of the manufacturer, new tools are not necessary to operate and monitor the device. The instrument developers also would use standard SuperMOCA interfaces and specifications as inputs to their design, and provide a virtual device for their instrument.

Mission requirements are used by project personnel to determine if any special and unique specifications or interfaces need to be added to SuperMOCA, if any standard SuperMOCA interface or specification requires modification, or if any unique interface or specification to the ground and/or spacecraft systems needs to be added outside of SuperMOCA. SuperMOCA is used for end-to-end testing and integration to demonstrate system compatibility, reliable data transport, and reliable control/monitor capabilities. Since control and data interfaces are standardized, testing should be easier to accomplish and complete, regression testing could be reduced, individual tests should be less complex, and the number of tests should be reduced when compared to testing a non-standard mission system. Standard interfaces reduce the dependency on the actual test environment, and with virtual device interfaces a *plug 'n play* method of testing and integration is introduced.

There are several phases that occur during the project I&T. They will be discussed in this scenario (see Figure 3-2):

- Development and Build Testing (There seems to be a culture in the space mission community to have tight control over subsystems at this initial phase in I&T. Developers rely on home-built GSE[1] systems and the motivation to switch to a project wide I&T system at this stage is not there. Thus for the time being this phase of I&T will not be discussed in this scenario).
- Subsystem Assembly and Testing
- Spacecraft Integration and Test
  - Subsystem Delivery
  - Spacecraft Assembly
  - Environmental Testing
- Ground System Integration and Test (For the present this phase of I&T is out of scope of this document so it will not be discussed in this scenario).
- Mission Operations Compatibility Testing
- DSN (or Van) Compatibility Testing
- Launch Site Testing (this will be covered in Section 4. LAUNCH OPERATIONS SCENARIO)

[1] Ground Support Equipment

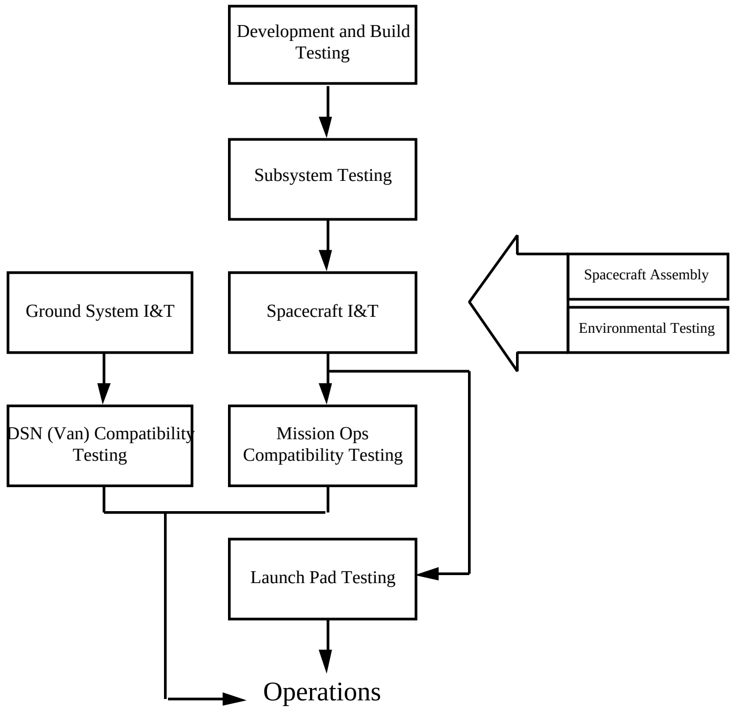

Figure 3-2 Phases of I&T

3.2.1 SUBSYSTEM ASSEMBLY AND TESTING

After the developers have verified the “board” level operation of their subsystem, they are ready to assemble their subsystem and verify its functionality under ambient and “space” conditions.

3.2.2 SPACECRAFT INTEGRATION AND TEST

This phase of I&T contains several sub-phases and can last from a few months to a few years depending on how much prior testing has been done.

3.2.2.1 Subsystem Delivery

At this stage, all the flight subsystems to be integrated are delivered. Assembly of the spacecraft begins. Before integration each subsystem undergoes an initial bench test and checkout to verify that the “box” was not damaged during shipment.

3.2.2.2 Spacecraft Assembly

Both electrical and mechanical integration of the spacecraft is done. Each subsystem undergoes a checkout that includes the following:

- Verification of software interfaces.
- Electrical performance functional test.
- Aliveness test.
- Short and Long form functional test.
- Diagnostic testing to verify standalone performance once integrated to the spacecraft.

Checkouts are run from paper procedures with each command entered by hand so they can be synchronized with the GSE. Electrical signals received upon command execution are recorded before, during, and after integration and compared.

Mechanical interfaces are also checked at this phase. These include:

- Interface fit check.
- Tolerance build-up check.
- Optical or mechanical critical alignment checks.

If the command and telemetry database has not been defined earlier, then it is usually done at this time, but in either case verification of the database is performed at this time. Test procedures required during environmental testing are also developed and verified at this time if not earlier.

3.2.2.3 Environmental Testing

Once the spacecraft has been assembled and subsystem functionality has been satisfied, environmental testing begins. Launch readiness, spacecraft system level requirements, and launch vehicle requirements are the major items to be verified at this phase of I&T.

Tests include the following:

- Electromagnetic interference and compatibility.
- Weight, mass properties and spin check.
- Vibration testing to include (aliveness tests between each axis test is usually performed to check for gross failures):
  - 3 axis random vibration, 3 axis sine burst, 3 axis mechanical shock.
- Thermal vacuum and thermal balance.
- Acoustic testing.
- Magnetic properties and magnetic calibration.
- Special tests, for example:
  - Orbit scenario tests (with the GSE simulating the solar arrays for example), radio frequency testing, high voltage testing, and telemetry verification.

A post environment checkout and characterization test is run to check for any degradation that might have occurred during this phase.

3.2.3 GROUND SYSTEM INTEGRATION AND TEST

This phase occurs in parallel to spacecraft integration and test and consists of development and build testing. Acceptance and operational testing is performed to check that the system requirements are satisfied. Finally integration of subsystem components to form an operational ground system is performed with end-to-end tests.

3.2.4 MISSION OPERATIONS COMPATIBILITY TESTING

External interfaces between the ground system, remote support sites, ground and space networks, and the spacecraft are exercised in this phase. Usually a suite of stored command loads developed earlier act as the test cases.

3.2.5 DSN (OR VAN) COMPATIBILITY TESTING

This phase is concerned with verifying that the spacecraft-ground station-network link is operational. Tests include:

- Uplink and downlink frequency tests.
- Modulation tests.
- Ranging requirement testing.

3.3 SUPERMOCA VIEWPOINT

The intent of this section is to provide a description of how a space mission that adheres to SuperMOCA interfaces and specifications could perform spacecraft integration and test.

Given these standards, Figure 3-1 would look like Figure 3-3. Testers need three things to test a subsystem: a way to communicate with the particular subsystem, a model of the external environment that the subsystem finds itself in, and a model of the rest of the system that the particular subsystem must interface with.

3.3.1 SUBSYSTEM ASSEMBLY AND TESTING

The purpose here is to verify the functionality of the subsystem under various conditions.

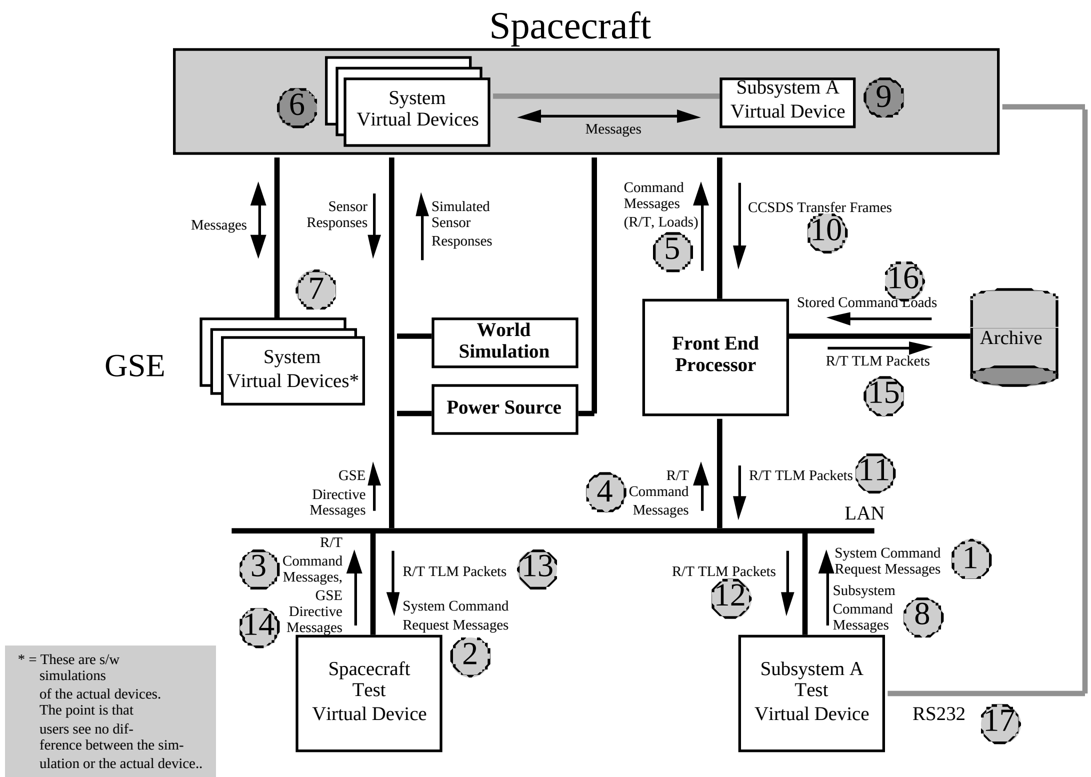

Figure 3-3 SuperMOCA Subsystem Assembly I&T

Refer to Figure 3-3 for the following discussion. The tester wants to test some capability on his subsystem. He might want to send directives to the system (see 1 in the figure) in order to initialize the system to a proper configuration so system directive requests are sent to the system test workstation (see 2 in the figure). The system workstation routes these system directives to the spacecraft (see 3, 4, and 5 in the figure). Virtual devices onboard the spacecraft (see 6 in figure) or simulated virtual devices (see 7 in the figure) receive the directives for execution. The tester is now ready to test the proper subsystem, here labeled A. Subsystem directives are sent to subsystem A (see 8, 4, and 5 in the figure) which receives the directives for execution (see 9 in the figure). Subsystem A then generates messages (command acknowledgment, measurements, diagnostics, ...) which are packetized and put into frames (see 10 in the figure). The GSE receives the frames, extracts the packets and forwards them to the originator (see 11 and 12 in the figure), or archives them for later use (see 15 in the figure).

In this phase of I&T it is also possible that a serial line connected directly to the device (see 17 in the figure) is also available in order to send directives and receive diagnostics to/from the device without the need to go through the GSE. An assumption made here is that at some point the tester would move towards communicating with his device through the nominal uplink path. This move would be made sometime after or during subsystem assembly.

The system test workstation also can send directives to the ground support equipment (see 14 in the figure).

Either of the test workstations can request canned command loads be sent by requesting the GSE to get the desired command loads from an archive (see 16 in the figure) for transmission to the spacecraft. Simulated sensor responses don't appear in the figure as they are out of the scope of SuperMOCA since these responses simulate the "real world" and devices don't interface with the real world through SuperMOCA. For example, a star field that is simulated by the GSE to test a star tracker device would not simulate inputs to the star tracker via SuperMOCA.

It is important here to realize that the user sees no difference (in terms of how to communicate with the device) between the virtual devices on board the spacecraft (see 6 in the figure) and the virtual devices that are being simulated (see 7 in the figure). The interfaces are the same and the communications protocols are the same by virtue of the fact that whether the virtual device is in "front" of a real device or a software simulation, both virtual devices would comply with SuperMOCA specifications.

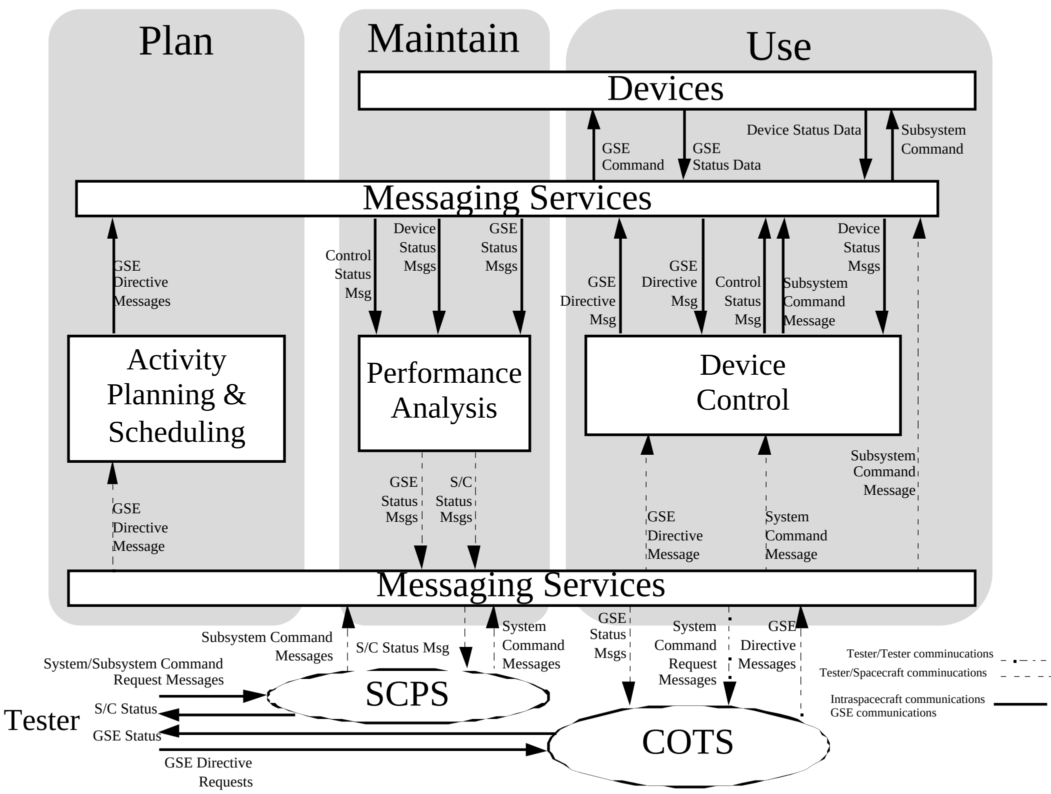

Figure 3-4 SuperMOCA Application of Subsystem Assembly I&T Interfaces

Refer to Figure 3-4 for the following discussion. This figure is an application of the interfaces in Figure 3-3 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The tester sends, via the local internet protocol, the required system directives necessary, if any, to configure the system to start the test. These directives are then uplinked to the spacecraft via SCPS. The directives needed to perform the test itself are sent to the device via SCPS or through the serial connection directly. System directives are sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these commands report their status (state change, diagnostics, and so on) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground upon execution of the test. The ground can alternately send the individual commands to the devices themselves.

Testers can also configure the GSE for subsystem assembly testing. The tester uplinks via the local internet protocol the required GSE directive messages to the Device Controller function of the I&T system (***Use*** in the figure). This function then sends the appropriate commands to the GSE components. The GSE reports back the status of the command execution. The GSE might be in use by multiple users, so some scheduling and planning might be required to control multiple tests being requested (***Plan*** in the figure).

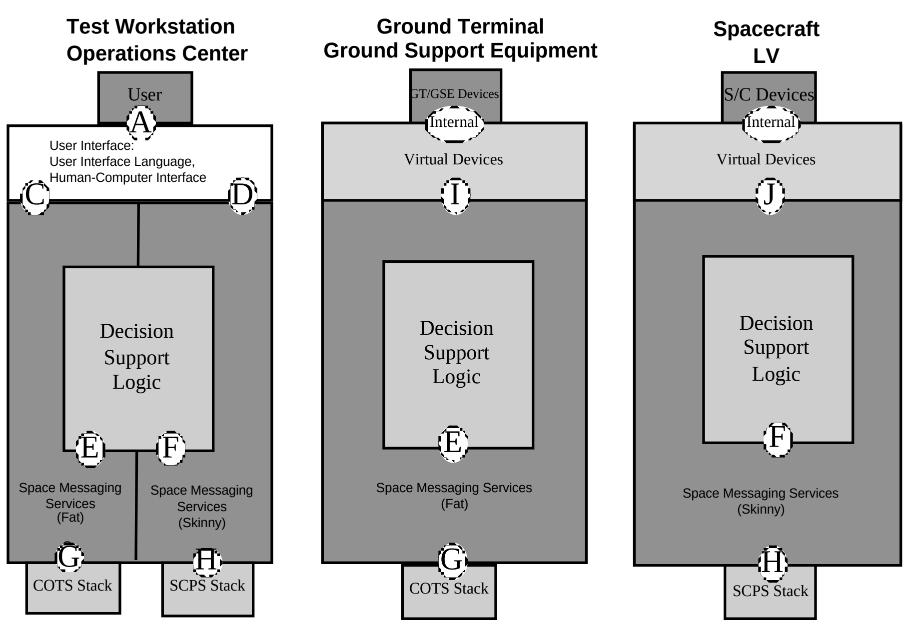

Figure 3-5 SuperMOCA Interface Types

Figure 3-5 is a depiction of the 10 different types of interfaces found in SuperMOCA compliant implementations. This figure will be used to identify the types of interfaces found in each I&T phase. This information will be used to identify what capabilities are needed for the space messaging system, and in turn will be used to write the specifications for the messaging system.

Table 3-1 below is a breakdown of the interface types for the Subsystem Assembly I&T phase.

Table 3-1 Subsystem Assembly I&T Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
GSE Command										✓
GSE Status Data										✓
Device Status Data										✓
Subsystem Command										✓
Device Status Msg									✓	
Subsystem Command Msg					✓		✓		✓	
Control Status Msg									✓	
GSE Directive Msg				✓		✓		✓		
GSE Status Msg						✓		✓		
S/C Status Msg							✓			
System Command Msg					✓		✓		✓	
System Command Req Msg					✓	✓				
System Command Request	✓	✓								
Subsystem Command Req	✓		✓		✓					
GSE Directive Request	✓			✓						
S/C Status Display to User	✓		✓							
GSE Status Display to User	✓	✓								

3.3.2 SPACECRAFT INTEGRATION AND TEST

3.3.2.1 Subsystem Delivery

The purpose here is to “bench test” all subsystems before integration begins to make sure they weren’t damaged during shipment.

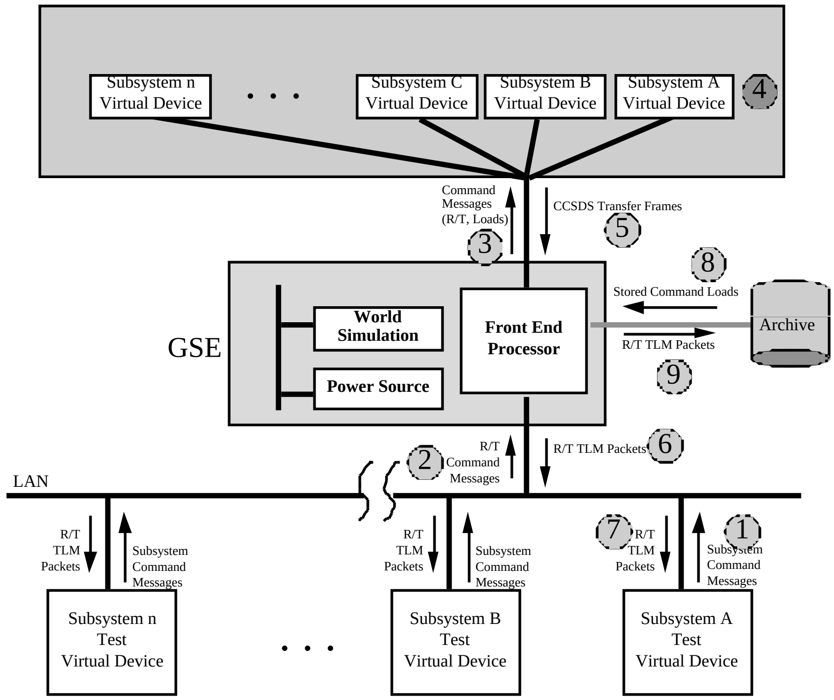

Figure 3-6 SuperMOCA Subsystem Delivery I&T

Refer to Figure 3-6 for the following discussion. The tester wants to test some capability on his subsystem post-shipment - usually a canned “aliveness” test. Subsystem directives are sent to subsystem A (see 1, 2, and 3 in the figure) which receives the commands for execution (see 4 in the figure). Subsystem A then generates messages (command acknowledgment, measurements, diagnostics, ...) which are packetized and put into frames (see 5 in the figure). The GSE receives the frames, extracts the packets and forwards them to the originator (see 6 and 7 in the figure), or archives them for later use (see 9 in the figure).

The tester can request canned command loads be sent by requesting the GSE to get the desired command loads from an archive (see 8 in the figure) for transmission to subsystem A.

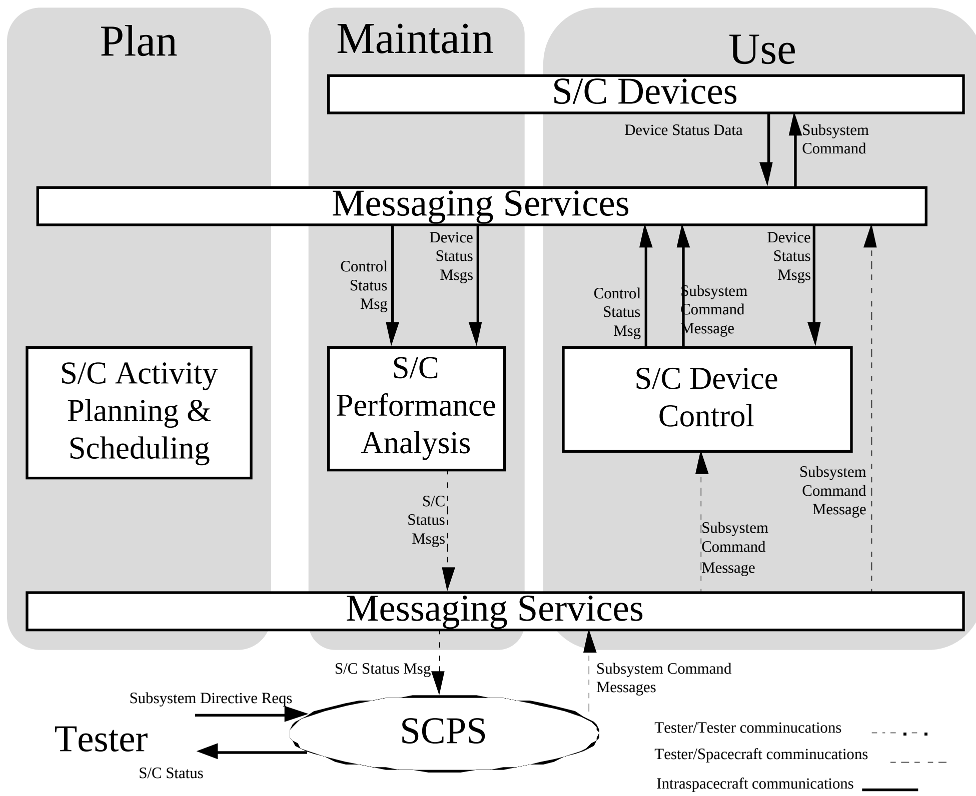

Figure 3-7 SuperMOCA Application of Subsystem Delivery I&T Interfaces

Refer to Figure 3-7 for the following discussion. This figure is an application of the interfaces in Figure 3-6 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The tester uplinks, via SCPS, the directives needed to perform the test. Subsystem directives can be sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (state change, diagnostics, and so on) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground upon execution of the test. The tester can alternately send the individual commands to the devices themselves. Note that the ***Plan*** function is not used for this phase of I&T.

Table 3-2 below is a breakdown of the interface types for the Subsystem Delivery I&T phase.

Table 3-2 Subsystem Delivery I&T Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
Device Status Data										✓
Subsystem Command										✓
Device Status Msg									✓	
Subsystem Command Msg					✓		✓		✓	
Control Status Msg									✓	
S/C Status Msg							✓		✓	
Subsystem Command Req	✓		✓		✓					
S/C Status Display to User	✓		✓							

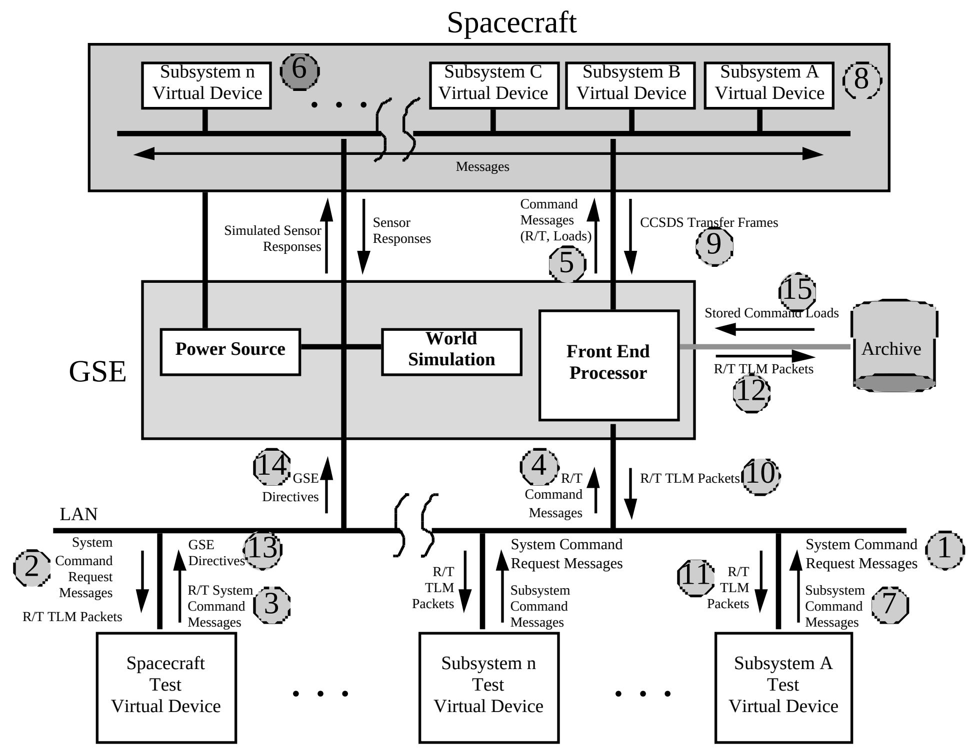

Figure 3-8 SuperMOCA Spacecraft Assembly I&T

3.3.2.2 Spacecraft Assembly

The purpose here is to perform electrical and mechanical integration of the spacecraft. This phase is similar to Subsystem Assembly except that in this phase all the flight subsystems are connected together for the first time. Aliveness, software interface and functionality tests are performed.

Refer to Figure 3-8 for the following discussion. The tester might want to send directives to the system (see 1 in the figure) in order to initialize the system to a proper configuration so system directive requests are sent to the system test workstation (see 2 in the figure). The system workstation routes these system directives to the spacecraft (see 3, 4, and 5 in the figure). Virtual devices onboard the spacecraft (see 6 in figure) receive the commands for execution. The tester is now ready to command his/her subsystem. Subsystem directives are sent (see 7, 4, and 5 in the figure) which are received by the subsystem for execution (see 8 in the figure). The subsystem then generates messages (command acknowledgment, measurements, diagnostics, ...) which are packetized and put into frames (see 9 in the figure). The GSE receives the frames, extracts the packets and forwards them to the originator (see 10 and 11 in the figure), or archives them for later use (see 12 in the figure).

The system test workstation also can send directives to the ground support equipment (see 13 and 14 in the figure) for needed support (simulated spacecraft orientation, power source configuration, and so on). The GSE might require some scheduling and planning as multiple testers might be involved in testing.

Either of the test workstations can request canned command loads be sent by requesting the GSE to get the desired command loads from an archive (see 15 in the figure) for transmission to the spacecraft.

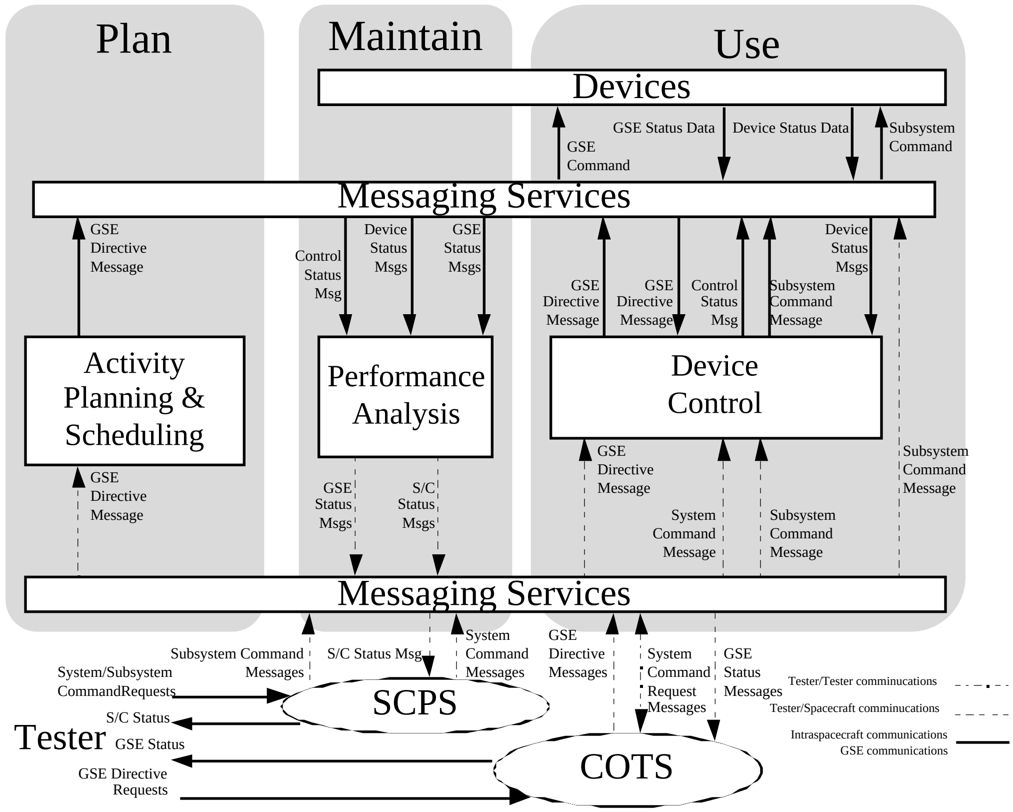

Figure 3-9 SuperMOCA Application of Spacecraft Assembly I&T Interfaces

Refer to Figure 3-9 for the following discussion. This figure is an application of the interfaces in Figure 3-8 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The tester uplinks, via the local internet protocol, the directives needed to perform the test. Subsystem directives can be sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground upon execution of the test. The tester can alternately send the individual commands to the devices themselves. Note that the ***Plan*** function is not used for this phase of I&T.

The tester can also request system directives in order to set the spacecraft to a prerequisite state if needed for the test to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Testers can also configure the GSE for spacecraft assembly testing. The tester uplinks via the local internet protocol the required GSE directive messages to the Device Controller function of the I&T system (***Use*** in the figure). This function then sends the appropriate directives to the GSE components. The GSE reports back the status of the command execution. The GSE might be in use by multiple users, so some scheduling and planning might be required to control multiple tests being requested (***Plan*** in the figure).

Table 3-3 below is a breakdown of the interface types for the Spacecraft Assembly I&T phase.

Table 3-3 Spacecraft Assembly I&T Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
GSE Command										✓
GSE Status Data										✓
Device Status Data										✓
Subsystem Command										✓
Device Status Msg									✓	
Subsystem Command Msg					✓		✓		✓	
Control Status Msg									✓	
GSE Directive Msg				✓		✓		✓		
GSE Status Msg						✓		✓		
S/C Status Msg							✓		✓	
System Command Msg					✓		✓		✓	
System Command Req Msg					✓	✓				
System Command Request	✓	✓			✓					
Subsystem Command Req	✓		✓		✓					
GSE Directive Request	✓			✓						
S/C Status Display to User	✓		✓							
GSE Status Display to User	✓	✓								

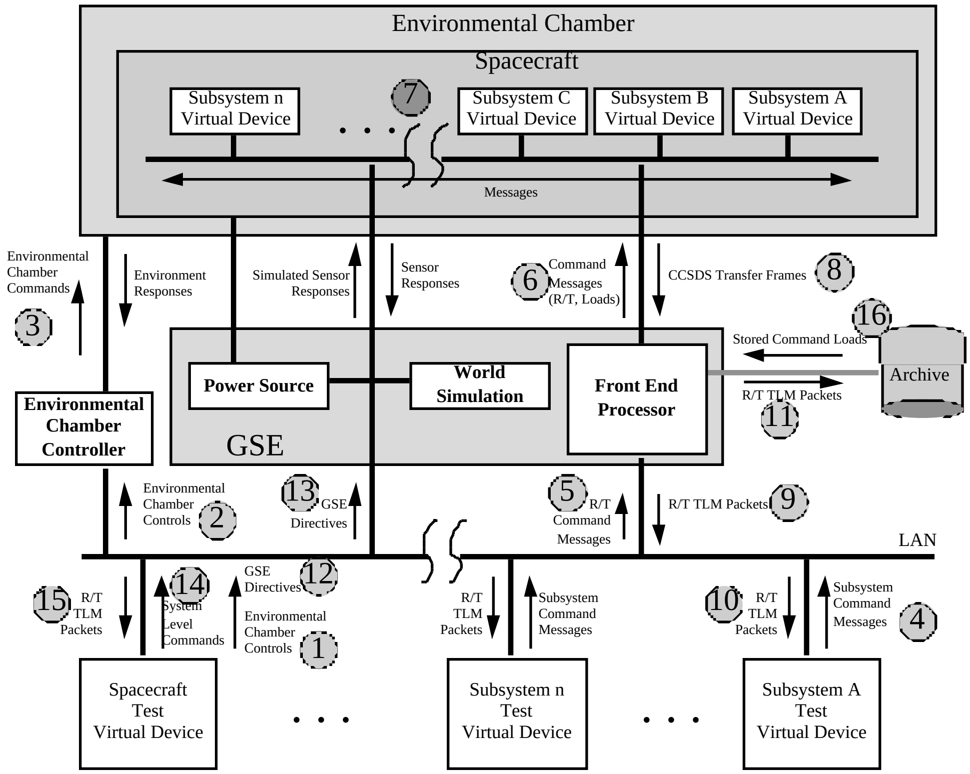

Figure 3-10 SuperMOCA Spacecraft Environmental I&T

3.3.2.3 Environmental Testing

The purpose here is to perform tests on the integrated spacecraft to see how it performs under flight conditions. Environments are designed to exercise the spacecraft under various situations: vibration, electromagnetic interference, thermal limits, acoustic performance. Also the spacecraft is characterized at this time: mass properties, weight balance, magnetic profile, and so on. Subsystems are tested after each environment test to check for failures or degraded performance. This testing is similar to Spacecraft assembly.

Refer to Figure 3-10 for the following discussion. The proper environment must be attained for the test to start (see 1, 2, and 3 in the figure). This might include vibration pallet directives (burst, sine wave, ...), or temperature settings, and so on, depending on the specific test. After the environmental test has ended. Subsystems are checked for any functional degradation (see 4, 5, and 6 in the figure). The commands are executed (see 7 in the figure) and responses are generated, packetized and placed into transfer frames and routed to the originator (see 8, 9, and 10 in the figure), or archived for later retrieval (see 11 in the figure). The tester might send directives to the system (see 14 in the figure) in order to initialize the system to a proper configuration. The system workstation routes these system directives to the spacecraft (see 5 and 6 in the figure). Virtual devices onboard the spacecraft (see 7 in figure) receive the commands for execution. The subsystems then generate messages (command acknowledgment, measurements, diagnostics, ...) which are packetized and put into frames (see 8 in the figure). The GSE receives the frames, extracts the packets and forwards them to the originator (see 9 and 15 in the figure), or archives them for later use (see 11 in the figure).

The system test workstation also can send directives to the ground support equipment (see 12 and 13 in the figure).

Either of the test workstations can request canned command loads be sent by requesting the GSE to get the desired command loads from an archive (see 16 in the figure) for transmission to the spacecraft.

Refer to Figure 3-11 to for the following discussion. This figure is an application of the interfaces in Figure 3-10 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The tester uplinks, via the local internet protocol, the directives needed to perform the test. Subsystem directives can be sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground upon execution of the test. The tester can alternately send the individual commands to the devices themselves.

The tester can also request system directives in order to set the spacecraft to a prerequisite state if needed for the test to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Testers can also configure the GSE for spacecraft assembly testing. The tester uplinks via the local internet protocol the required GSE directive messages to the Device Controller function of the I&T system (***Use*** in the figure). This function then sends the appropriate commands to the GSE components. The GSE reports back the status of the command execution. The GSE might be in use by multiple users, so some scheduling and planning might be required to control multiple tests being requested (***Plan*** in the figure).

Testers can also configure the Environmental chambers for spacecraft testing. The tester uplinks via the local internet protocol the required Environmental chamber directives to the Device Controller function of the I&T system (***Use*** in the figure). This function then sends the appropriate commands to the Environmental chamber controller.

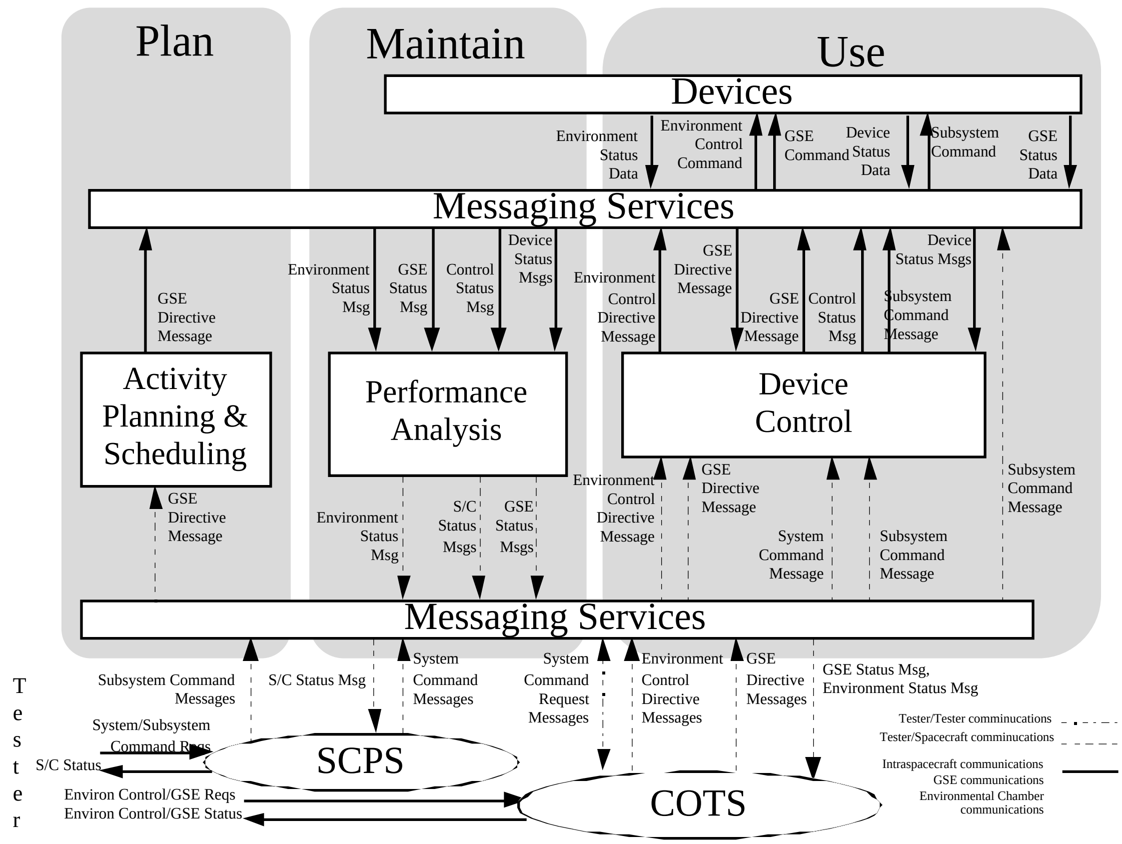

Figure 3-11 SuperMOCA Application of Spacecraft Environmental I&T Interfaces

Table 3-4 below is a breakdown of the interface types for the Spacecraft Environmental I&T phase.

Table 3-4 Spacecraft Environmental I&T Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
GSE Command										✓
GSE Status Data										✓
Device Status Data										✓
Environment Control Cmd										✓
Environment Status Data										✓
Subsystem Command										✓
Device Status Msg									✓	
Subsystem Command Msg					✓		✓		✓	
Control Status Msg									✓	
Environment Control				✓		✓		✓		

	A	C	D	E	F	G	H	I	J	Internal
Directive Msg										
GSE Directive Msg				✓		✓		✓		
Environment Status Msg				✓		✓		✓		
GSE Status Msg						✓		✓		
S/C Status Msg							✓		✓	
System Command Msg					✓		✓		✓	
System Command Req Msg					✓	✓				
System Command Request	✓	✓			✓					
Subsystem Command Req	✓		✓		✓					
GSE Directive Request	✓			✓						
S/C Status Display to User	✓		✓							
GSE Status Display to User	✓	✓								
Environment Control Directive Request	✓	✓		✓						
Environment Control Status Display to User	✓	✓								

3.3.3 GROUND SYSTEM INTEGRATION AND TEST

The ground components of the mission system are developed, tested, and integrated usually in parallel to spacecraft I&T. For the present this phase of I&T is out of scope of this document. However there are interactions to note between this phase and the testing and integration of the spacecraft:

- Spacecraft and payload commands are usually needed for ground system development and testing.
- Ground systems that perform memory management of on board systems need close spacecraft engineering support for development and testing.
- Also, if the ground system models any portion of the spacecraft, engineering support is usually needed for development and testing.
- Mission Operations Compatibility Testing

In this phase of testing, the ground components are exercised in and end-to-end-fashion and includes data networks (both ground and space), ground support sites, and ground terminals. Sometimes stored command loads (developed during ground system I&T) are used to test the functionality of the Mission Operations system.

Refer to Figure 3-12 for the following discussion. A remote site might want to send commands to some particular subsystem or set of subsystems, e.g., system level commands (see 1 in the figure). External networks or even space networks may be used in order for the command request messages to be received by the Ground System (see 2 in the figure). The Command Processor handles the requests and routes the commands to the spacecraft (see 3 and 4 in the figure).

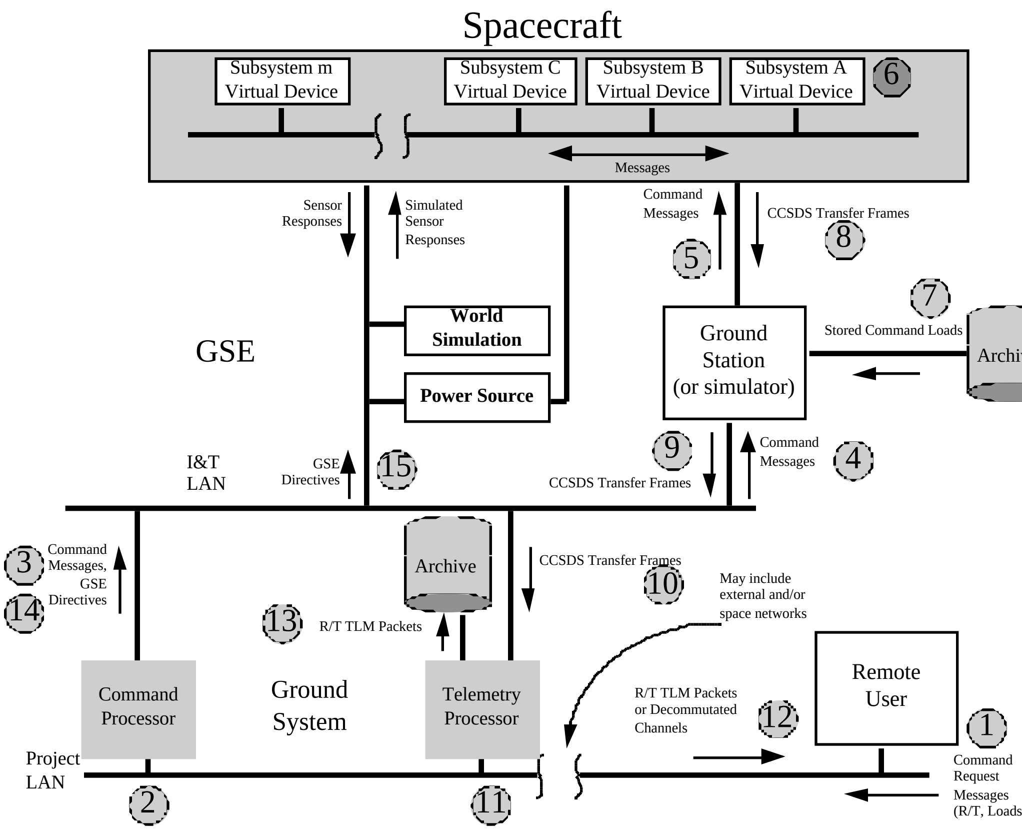

Figure 3-12 SuperMOCA Mission Operations Compatibility Testing

Either a ground terminal or a ground terminal simulator is placed in-line which receives the directives to uplink to the spacecraft (see 5 in the figure). Virtual devices onboard the spacecraft (see 6 in figure) receive the commands for execution. The subsystem(s) then generate(s) messages (command acknowledgment, measurements, diagnostics, ...) which are packetized and put into frames (see 8 in the figure). The ground terminal receives the frames and sends them to the Ground System processors (see 9 and 10 in the figure). The Ground System can archive the telemetry for later use (see 13 in the figure). The Ground System telemetry processor (see 11 in the figure) then routes the packets to the originator or decommutates the telemetry for channel display to the user (see 12 in the figure).

The system test workstation also can send directives to the ground support equipment (see 14 and 15 in the figure).

Either or the test workstations can request canned command loads be sent by requesting the GSE to get the desired command loads from an archive (see 7 in the figure) for transmission to the spacecraft.

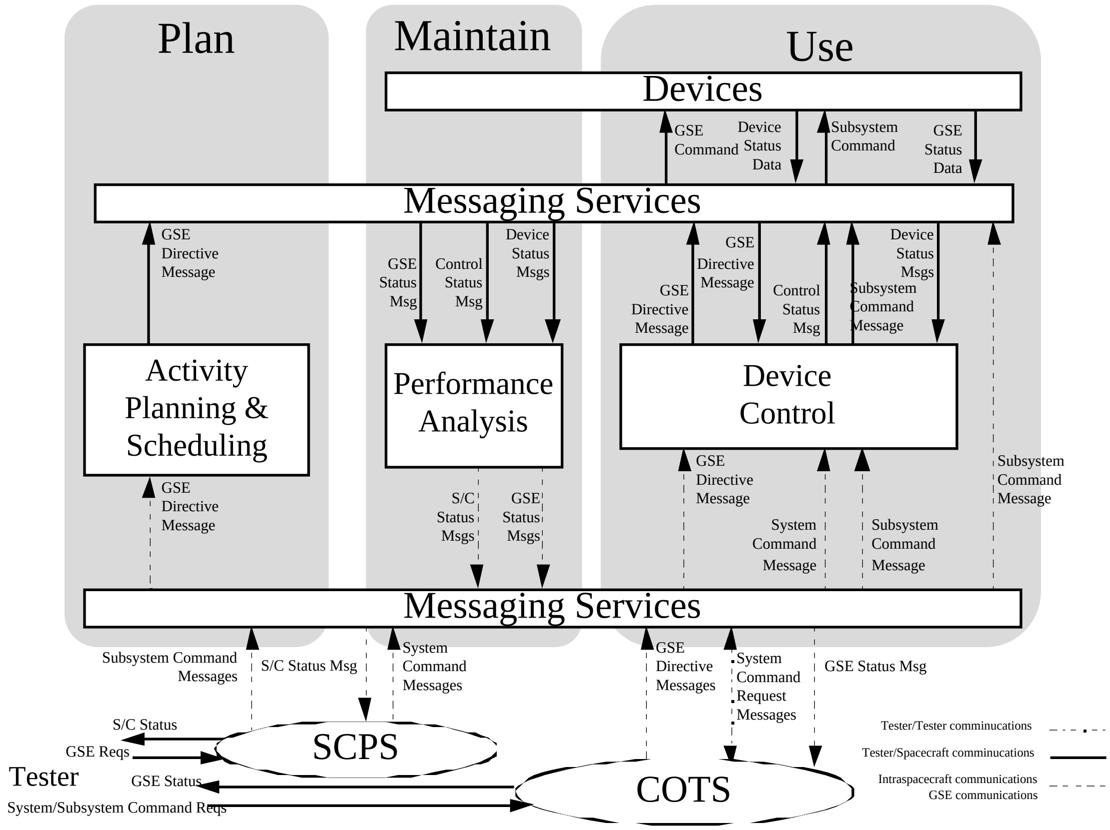

Figure 3-13 SuperMOCA Application of Mission Operations Compatibility Testing Interfaces

Refer Figure 3-13 to for the following discussion. This figure is an application of the interfaces in Figure 3-12 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The tester (who may be at a remote site) sends to the Ground System, via the local internet protocol, the directives needed to perform the test. The Command Processor routes the directives to the ground terminal, via the local internet protocol, which uplinks them via SCPS to the spacecraft. Subsystem directives are sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground, via SCPS, upon execution of the test. The tester can alternately send the individual commands to the devices themselves.

The tester can also request system directives in order to set the spacecraft to a prerequisite state if needed for the test to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Testers can also configure the GSE for spacecraft assembly testing. The tester sends via the local internet protocol the required GSE directive messages to the Device Controller function of the I&T system (***Use*** in the figure). This function then sends the appropriate commands to the GSE components. The GSE reports back the status of the command execution. The GSE might be in use by multiple users, so some scheduling and planning might be required to control multiple tests being requested (***Plan*** in the figure).

Table 3-5 below is a breakdown of the interface types for the Mission Operations Compatibility Testing phase.

Table 3-5 Mission Operations Compatibility Testing Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
GSE Command										✓
GSE Status Data										✓
Device Status Data										✓
Subsystem Command										✓
Device Status Msg									✓	
Subsystem Command Msg							✓		✓	
Control Status Msg									✓	
GSE Directive Msg				✓		✓		✓		
GSE Status Msg						✓		✓		
S/C Status Msg							✓		✓	
System Command Msg					✓		✓		✓	
System Command Req Msg					✓	✓				
System Command Request	✓	✓			✓					
Subsystem Command Req	✓		✓		✓					
GSE Directive Request	✓			✓						
S/C Status Display to User	✓		✓							
GSE Status Display to User	✓	✓								

3.3.4 DSN (OR VAN) COMPATIBILITY TESTING

The purpose here is to test the link between the ground terminal and the spacecraft. Command reception/acknowledgment or telemetry reception is not tested here.

Refer to Figure 3-14 for the following discussion. Since this phase of I&T is concerned mainly with frequency, modulation, and ranging interfaces, the Ground System command and telemetry processors are not exercised. The ground terminal generates an uplink frequency (see 1 in the figure) and waits for the spacecraft to lock on to the carrier. On board the spacecraft, the uplink carrier frequency is multiplied by some factor and the spacecraft's transponder (see 2 in the figure) generates a downlink carrier with this frequency (see 3 in the figure). This is done for each modulation phase angle. If there is a space terminal to be used then basically the same thing is done but instead of a ground terminal, the space terminal-spacecraft link is tested (see 4, 2, and 5 in the figure).

The tester uses the system test workstation to generate configuration directives for the ground terminals and if required the space terminals (see 6 in the figure) to test carrier frequency, carrier modulation, and ranging tone interfaces. The ground terminal generates status messages (configuration change confirmation, diagnostics) to inform the tester the results of the tests (see 7 in the figure).

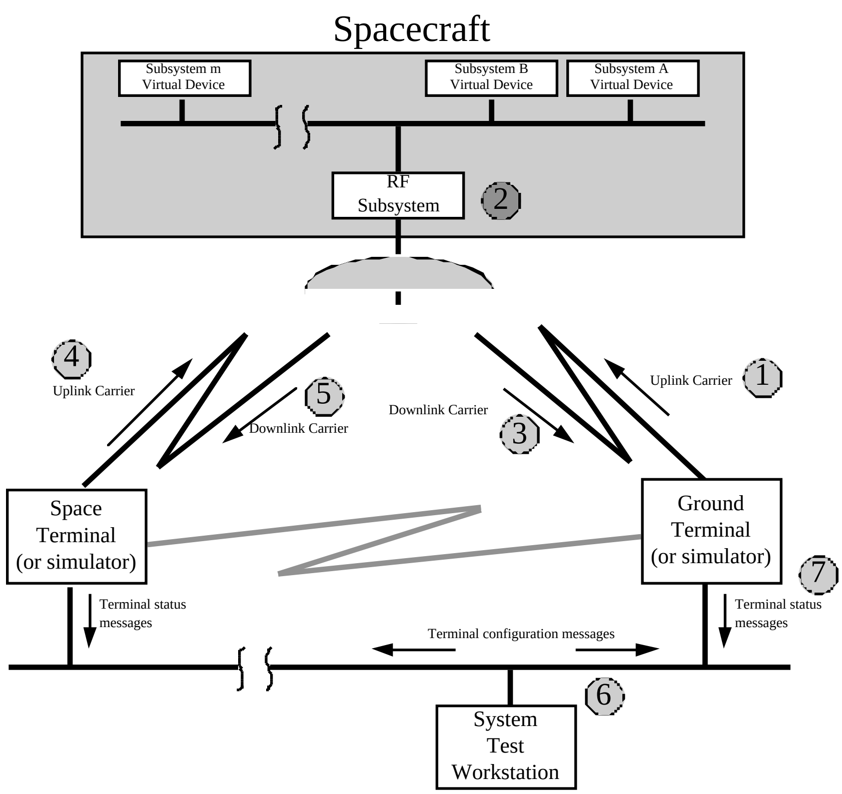

Figure 3-14 SuperMOCA DSN (Van) Compatibility Testing

Refer Figure 3-15 to for the following discussion. This figure is an application of the interfaces in Figure 3-14 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The tester sends to the ground (or space) terminals, via the local internet protocol, the directives needed to configure the ground terminal to perform the test. Configuration directives are sent to the Device Control function (***Use*** in the figure). The Device Control function then computes and sends the actual commands to the various devices in the ground terminal. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report, via the local internet protocol, upon execution of the test. Note that the ***Plan*** function is not used for this phase of I&T.

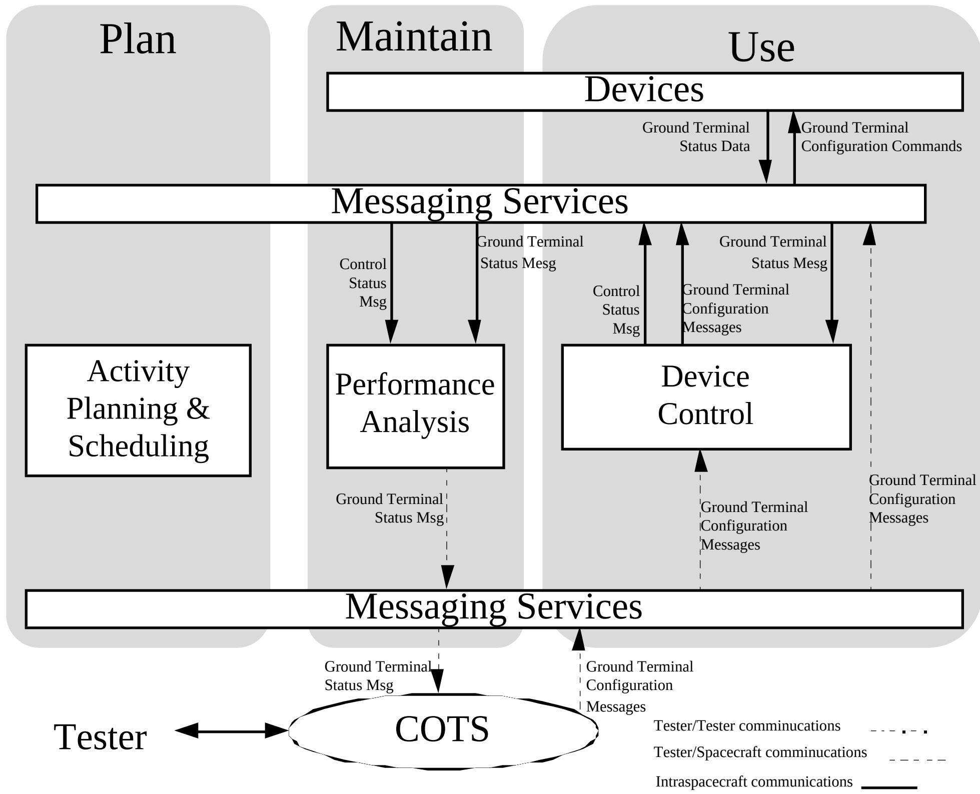

Figure 3-15 SuperMOCA Application of DSN (Van) Compatibility Testing Interfaces

Table 3-6 below is a breakdown of the interface types for the DSN (Van) Compatibility Testing phase.

Table 3-6 DSN (Van) Compatibility Testing Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
Ground Terminal Configuration Command										✓
Ground Terminal Status Data										✓
Ground Terminal Status Msg						✓		✓		
Ground Terminal Configuration Msg				✓		✓		✓		

	A	C	D	E	F	G	H	I	J	Internal
Control Status Msg								✓		
Ground Terminal Configuration Request	✓	✓		✓						
Ground Terminal Status Display to User	✓	✓								

3.4 SUMMARY OF SUPERMOCA VIEW OF SPACECRAFT I&T

Refer to Figure 3-5 for the following discussion. Table 3-7 below summarizes the interface types that are found in the spacecraft I&T phase of a mission from the SuperMOCA perspective. It shows that most of the 168 interfaces are type A (interfaces to/from the user) with type J (to/from virtual devices onboard the spacecraft) following closely. This is as expected since the problem that SuperMOCA addresses in this I&T scenario is for the most part the monitor and control of onboard devices.

Since the two most common types of interfaces are A and J, it can be inferred that the **User to Control Interface Language** interface and **the SMS to onboard Virtual Device** interface are both very important to the success of SuperMOCA. This also means that issues like performance, functionality, and operability become critical at these junctures. Specifications for these two interface types (A and J) must be given close attention and become at least for the I&T phase of a mission crucial to the success of SuperMOCA.

Table 3-7 Summary of Interface Types for Spacecraft I&T

	A	C	D	E	F	G	H	I	J	Internal
Number of Interfaces	**26**	**11**	**10**	**13**	**20**	**16**	**14**	**13**	**23**	**22**
% of Total Interfaces	**16%**	**6%**	**6%**	**8%**	**12%**	**10%**	**8%**	**8%**	**13%**	**13%**

4. LAUNCH OPERATIONS SCENARIO

4.1 INTRODUCTION

This section presents an operational scenario for the launch phase of a mission from the perspective of the space system user (e.g. launch team member). The space mission components that are available to the user include the launch facility, ground system, ground terminals, launch vehicle, and the spacecraft. The scenario examines how SuperMOCA could improve launch operations by lowering costs.

4.2 MISSION PHASE VIEWPOINT

After spacecraft integration and test is completed, the launch phase begins with the launch countdown and ends with spacecraft separation from the launch vehicle. For this scenario, the mating of the spacecraft with the launch vehicle will be included in this discussion. During the launch phase, the spacecraft is in a minimal operating mode providing telemetry. SuperMOCA provides standard interfaces on-board the spacecraft, on-board the launch vehicle, in the ground system, in the launch facility, and the protocols used to send data to the ground.

This scenario includes the following phases:

- Spacecraft and Launch Vehicle Integration
- Launch Pad Operations
- Spacecraft Separation

This scenario will be divided into two parts: Shuttle Mission Payloads and Expendable Launch Vehicle Missions

4.2.1 SHUTTLE MISSIONS

Kennedy Space Center (KSC) is the launch site for Space Shuttle missions. Expendable launch vehicle missions can be processed and lifted into orbit from many different launch sites. Final checkout, preparation, and loading of payloads in the launch vehicle is performed at the launch site according to customer specified requirements

Testing for shuttle missions provides the capability to monitor and control the operation of the spacecraft (referred to as a payload at KSC) prior to its installation in the shuttle cargo bay. The provided capabilities include:

- Data acquisition and monitoring
- Command and control processing
- Archival and retrieval, and
- Test application development.

If there is a requirement to test unique and custom interfaces on a spacecraft, the ground system must be modified to add that interface capability to the system.

Shipment of the spacecraft to the launch site begins this phase of Launch Operations. Testing in this phase includes:

- Initial checkout upon arrival.
- Interface and operational verification tests.
- Shuttle and payload checkout includes:
  - Interface verification and launch separation sequence testing.
  - Launch countdown tests and liftoff sequence tests.

Once the payload is integrated into the Shuttle's payload bay no commanding of the payload is permitted.

4.2.1.1 Spacecraft and Shuttle Integration

If the payload will interface with shuttle systems, those shuttle avionics and power interfaces to the payload are tested through simulation of shuttle interfaces using a high-fidelity mock-up of the shuttle payload bay. This mock-up duplicates physical dimensions and selected fluid, electrical, mechanical, and software interfaces between the shuttle and payload elements. If more than one payload is carried on one mission, compatibility of these payloads is included in the pre-launch testing. Launch countdown dress rehearsals are done as well as launch sequence and separation sequence testing. If required, the payload is fueled prior to installation in the shuttle payload bay.

After integration in the shuttle cargo bay, a spacecraft-to-shuttle interface verification test is performed. An optional end-to-end communications test may be performed between the spacecraft and its ground terminal. This test can include up-link and down-link communication to verify spacecraft-to-ground terminal compatibility. In support of this test, a spacecraft console is provided and operated by launch site personnel in the launch control center to monitor and control specific payload functions. No access or external power supply to the spacecraft is planned after this stage. Spacecraft subsystems that need to be operated continuously during this time until launch require internal battery packs, or special support. The shuttle is then towed to the vehicle assembly building for integration with the external tank and solid rocket boosters.

4.2.1.2 Launch Pad Operations

During rollout from the assembly building to the launch pad, there is no standard capability to power up or monitor spacecraft elements. On the pad prior to launch, active payload systems may be monitored through shuttle systems. After the shuttle is delivered to the launch pad a launch readiness verification test is conducted. The normal processing flow does not include access to the payload bay while the shuttle is on the pad.

All elements of shuttle control are transferred to the mission control center at Johnson Space Center from the time the shuttle has cleared the launch tower. For the duration of the on-orbit phase of the mission, spacecraft-related transmissions are linked to the payload ground terminal. Launch site user rooms are able to monitor but not communicate with the spacecraft.

4.2.1.3 Spacecraft Separation

Where payloads don't separate from the Shuttle, then nominal orbital operations start at this point (go on to Section 5 for a thorough discussion on post-launch mission operations).

If the payload does separate from the Shuttle Payload Bay, the payload is usually operating from stored command scripts. Ground terminal coverage is usually continuous. Commanding is possible but very limited (e.g., a go-no go separation command may be uplinked at this time) and telemetry is being received.

4.2.2 EXPENDABLE LAUNCH VEHICLE MISSIONS

Testing for expendable launch vehicle missions varies according to three classes of spacecraft.

Commercial missions typically have the majority of spacecraft assembly and testing completed at the manufacturing facility. The primary functions performed at the launch site are hazardous fueling, encapsulation, and launch.

Military missions are typically contracted through a commercial satellite manufacturer who accomplishes the majority of spacecraft assembly and testing at the manufacturing facility. The manufacturer performs a minimum set of non-hazardous testing at the launch site. The spacecraft is then fueled, encapsulated, and launched.

Government missions typically include extensive testing at the launch site. Every system level test at the system/bus level is repeated at the launch site. The spacecraft is then fueled, encapsulated, and launched.

Shipment of the spacecraft to the launch site begins this phase of Launch Operations. Testing in this phase includes:

- Initial checkout upon arrival.
- Interface and operational verification tests.
- Launch vehicle and payload checkout includes:
  - Interface verification and launch separation sequence testing.
  - Launch countdown tests and liftoff sequence tests.

4.2.2.1 Spacecraft and Launch Vehicle Integration

If the payload will interface with launch vehicle systems, those launch vehicle avionics and power interfaces to the payload can be tested through simulation of launch vehicle interfaces. This simulation duplicates selected fluid, electrical, mechanical, and software interfaces between the launch vehicle and payload elements. Launch countdown dress rehearsals are done as well as launch sequence and separation sequence testing. If required, the payload is fueled prior to mating with the launch vehicle.

After integration with the launch vehicle, a spacecraft to launch vehicle interface verification test is performed. An optional end-to-end communications test may be performed between the spacecraft and its ground terminal. This test can include up-link and down-link communication to verify spacecraft-to-ground terminal compatibility. In support of this test, a spacecraft console is provided and operated by launch site personnel in the launch control center to monitor and control specific payload functions. No access or external power supply to the spacecraft is planned after this stage. Spacecraft subsystems that need to be operated continuously during this time until launch require internal battery packs, or special support. The launch vehicle is then towed to the launch pad.

4.2.2.2 Launch Pad Operations

During rollout to the launch pad, there is no standard capability to power up or monitor spacecraft elements. On the pad prior to launch, active payload systems may be monitored through the launch facility systems. After the launch vehicle is delivered to the launch pad a launch readiness verification test is conducted.

All elements of mission control are transferred to the mission control center at the project's designated center from the time the spacecraft has cleared the launch tower.

4.2.2.3 Spacecraft Separation

During this activity the payload is usually operating from stored command scripts. Ground terminal coverage is usually continuous. Commanding is possible but very limited (e.g., a go-no go separation command may be uplinked at this time) and telemetry is being received.

4.3 SUPERMOCA VIEWPOINT

The intent of this section is to provide a description of how a space mission that adheres to SuperMOCA interfaces and specifications could perform launch pad operations.

Missions have limited access to the spacecraft during this phase.

4.3.1 SHUTTLE MISSIONS

Shipment of the spacecraft to the launch site begins this phase of Launch Operations. Testing in this phase includes:

- Initial checkout upon arrival.
- Interface and operational verification tests.

- Shuttle and payload checkout includes:
  - Interface verification and launch separation sequence testing.
  - Launch countdown tests and liftoff sequence tests.

4.3.1.1 Spacecraft and Shuttle Integration

Refer to Figure 4-1 for this discussion. Before integration with the Shuttle, the spacecraft and Shuttle interfaces are verified using a Shuttle mock up of the payload bay. After Shuttle integration the set of verification tests may be repeated. Canned sequences, e.g., payload separation, are loaded into the spacecraft pre-launch. When the tests are executed, telemetry generated by the Shuttle and/or Shuttle mock up and the spacecraft is received by the launch facility while on the ground (see 1 and 2 in the figure). The launch facility separates the Shuttle and spacecraft telemetry. The ground system's telemetry processor then extracts the spacecraft packets (see 3 and 4 in the figure). The ground system then routes the packets to the user who may be at a remote site (see 5 in the figure). If there is any Shuttle pre test commanding, Shuttle personnel are responsible for those directives (see 6 in the figure).

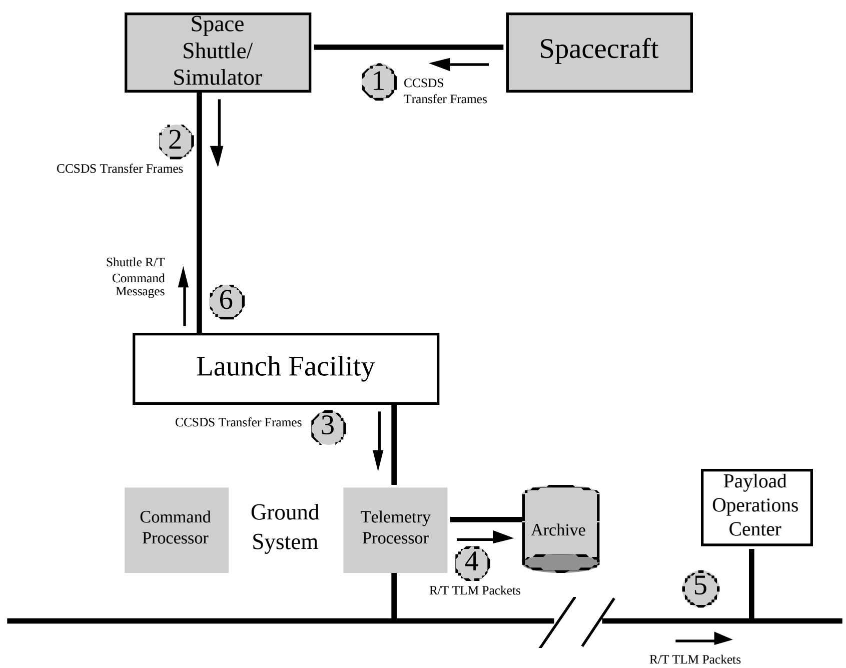

Figure 4-1 SuperMOCA Spacecraft and Shuttle Integration

Refer to Figure 4-2 for the following discussion. This figure is an application of the interfaces in Figure 4-1 to the Plan, Use, Maintain SuperMOCA concept for Spacecraft and Shuttle Integration. The directives needed to perform the test are stored pre launch in the spacecraft. Subsystem directives are sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground, via SCPS, upon execution of the test. Shuttle directives are uplinked via SCPS if required to set the Shuttle to some prerequisite state pre-test. Note that the ***Plan*** function is not used for this phase.

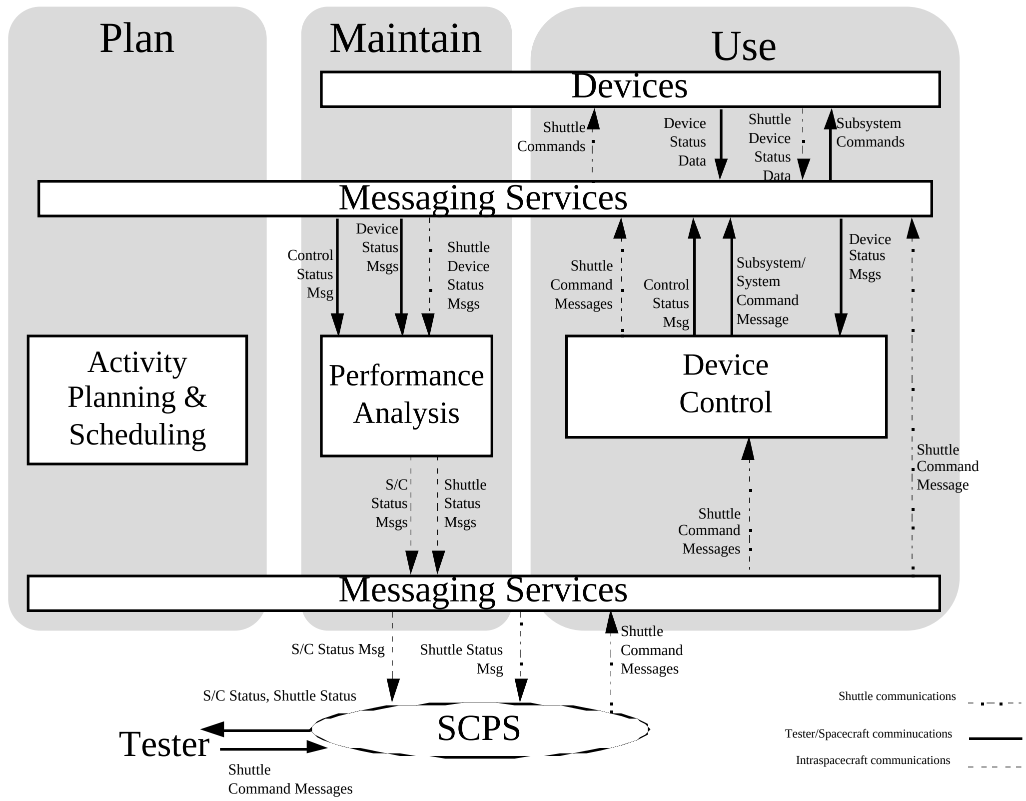

Figure 4-2 SuperMOCA Application of Spacecraft and Shuttle Integration Interfaces

System directives in the stored command loads are used in order to set the spacecraft to a prerequisite state if needed for the test to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Table 4-1 below is a breakdown of the interface types for the Shuttle/Payload Integration phase.

Table 4-1 Shuttle/Payload Integration Interfaces by Type

	A	C	D	E	F	G	H	I	J	Intern al

	A	C	D	E	F	G	H	I	J	Internal
Device Status Data										✓
Shuttle Device Status Data										✓
Subsystem Commands										✓
Shuttle Commands										✓
Device Status Msgs									✓	
Shuttle Device Status Msgs									✓	
Subsystem Command Msgs					✓				✓	
Shuttle Command Msgs					✓					
Control Status Msgs									✓	
S/C Status Msgs							✓		✓	
Shuttle Status Msgs							✓			
System Command Msgs					✓				✓	
S/C Status Display to User	✓		✓							
Shuttle Status Display to User	✓		✓							
Shuttle Command Req	✓		✓	✓						

4.3.1.2 Launch Pad Operations

Refer to Figure 4-3 for this discussion. On the pad prior to launch, active payload systems may be monitored through shuttle systems (see 1 and 2 in the figure). No payload commanding is permitted.

During Shuttle/payload verification tests telemetry generated by the Shuttle and the spacecraft is received by the launch facility while on the ground (see 1 and 2 in the figure). The launch facility separates the Shuttle and spacecraft telemetry. The ground system's telemetry processor then extracts the spacecraft packets (see 4 and 5 in the figure). The ground system then routes the packets to the user who may be at a remote site (see 5 in the figure).

After launch, telemetry is received by the launch facility tracking stations (and later by the ground stations via the TDRSS, see 6 and 7 in the figure), processed by the ground system, and received by the users (see 5 in the figure). Shuttle state vectors are received by the launch facility for orbit injection determination (see 2 and 6 in the figure).

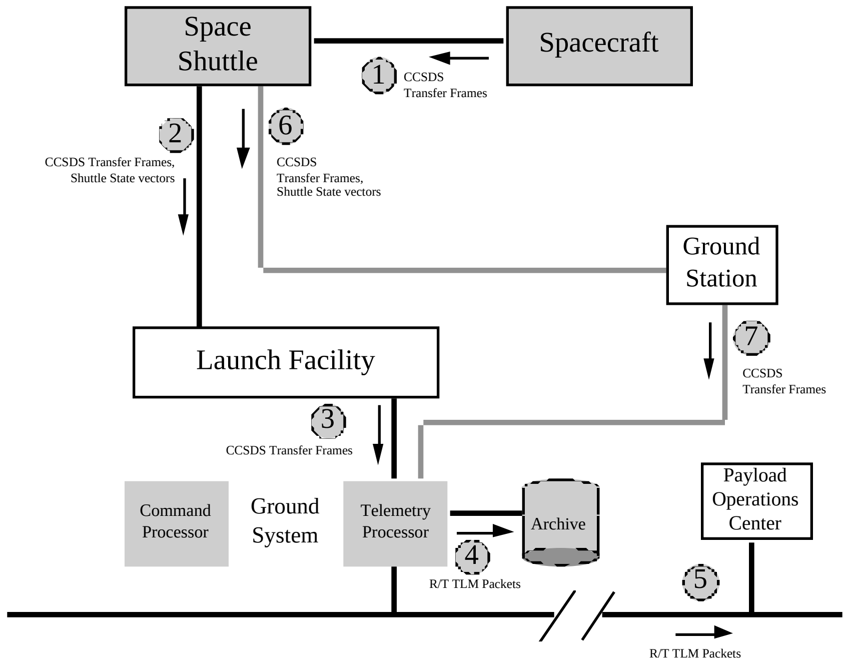

Figure 4-3 SuperMOCA Shuttle Launch Pad Operations

Refer to Figure 4-4 for the following discussion. This figure is an application of the interfaces in Figure 4-3 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. Payload devices during this phase of launch operations are not being commanded and only report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can issue a summary report to the ground, via SCPS. Note that the ***Plan*** function is not used for this phase.

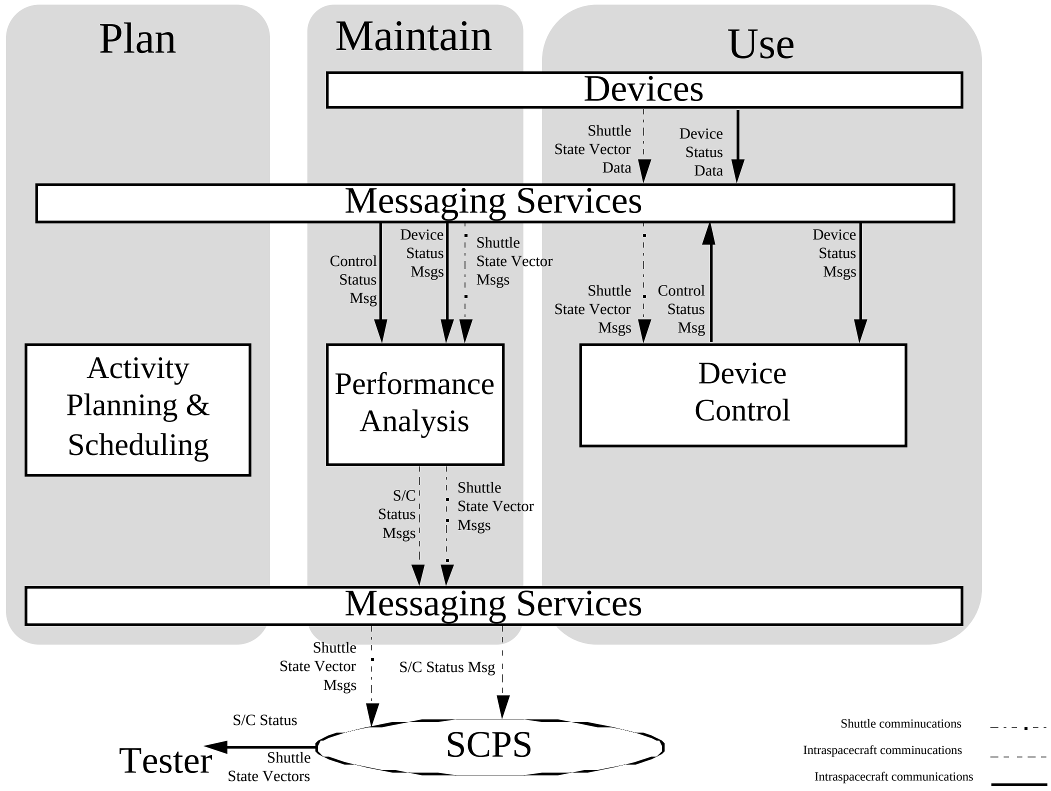

Figure 4-4 SuperMOCA Application of Launch Pad Operations Interfaces

Table 4-2 below is a breakdown of the interface types for the Launch Pad Operations phase.

Table 4-2 Launch Pad Operations Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
Shuttle State Vector Data										✓
Device Status Data										✓
Device Status Msg									✓	
Control Status Msg									✓	
Shuttle State Vector Msg							✓		✓	
S/C Status Msg							✓		✓	
S/C Status Display to User	✓		✓							
LV State Vector Display to User	✓		✓							

4.3.1.3 Spacecraft Separation

Refer to Figure 4-5 for this discussion. Payload separation sequences, are loaded into the spacecraft pre-launch. When executed, telemetry generated by the Shuttle and the spacecraft is received by the ground station (see 1 and 2 in the figure). The ground system's telemetry processor extracts the spacecraft packets (see 3 and 4 in the figure) then routes the packets to the user who may be at a remote site (see 5 in the figure). If there is any spacecraft commanding, e.g., a go-separation directive (see 6, 7, 8, and 9 in the figure) then the Project Operations Center uplinks directives through the ground station and Shuttle.

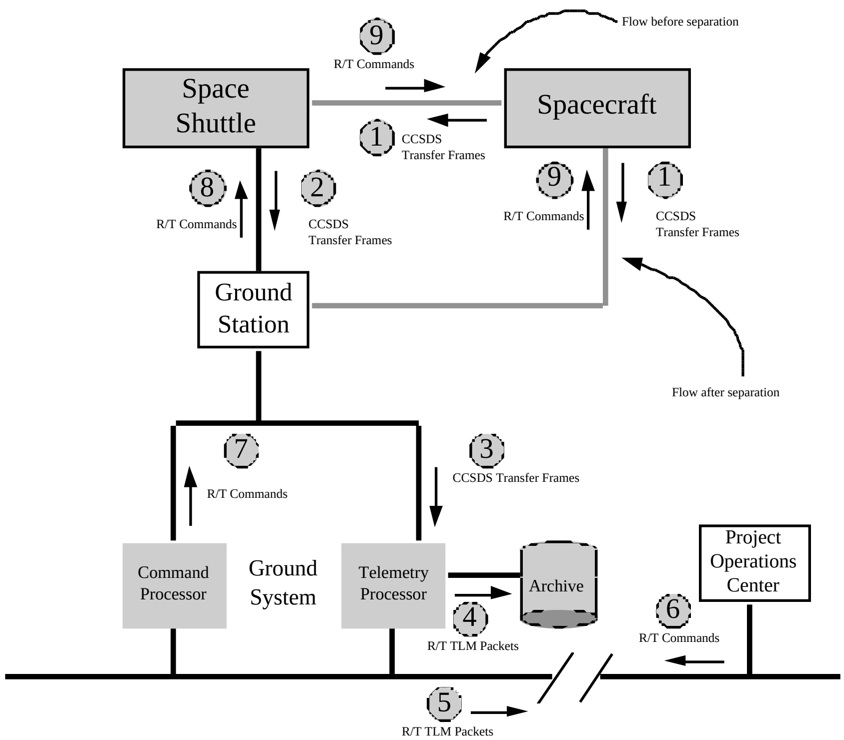

Figure 4-5 SuperMOCA Shuttle/Payload Separation

Refer to Figure 4-6 for the following discussion. This figure is an application of the interfaces in Figure 4-5 to the Plan, Use, Maintain SuperMOCA concept for Spacecraft and Shuttle Separation. The directives needed to perform the separation are stored pre launch on board the spacecraft. Subsystem directives are sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can issue a summary report to the ground, via SCPS, during and after execution of the separation.

Shuttle directives are uplinked via SCPS if required to perform the payload separation. The Shuttle devices upon execution of these commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the Shuttle devices and can issue a summary report to the ground, via SCPS, after execution of the separation. Note that the ***Plan*** function is not used for this phase.

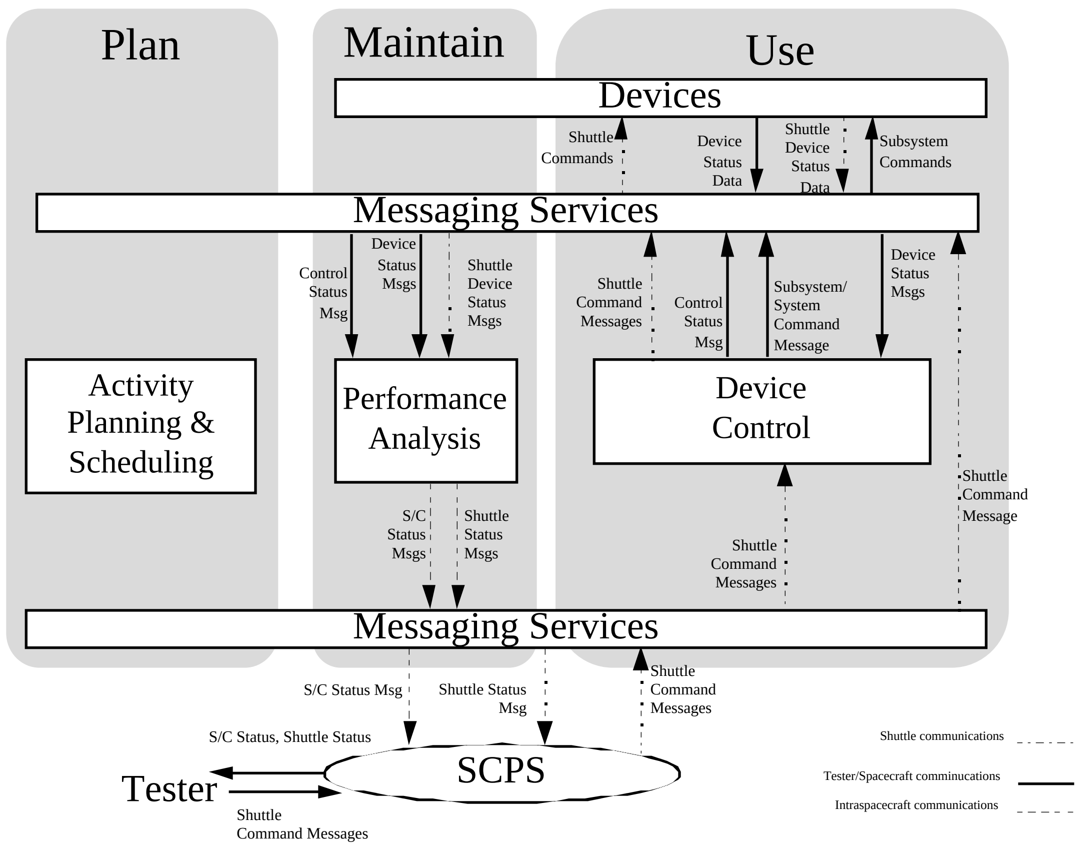

Figure 4-6 SuperMOCA Application of Shuttle/ Spacecraft Separation Interfaces

System directives in the stored command loads are used in order to set the spacecraft to a prerequisite state if needed for the separation to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Table 4-3 below is a breakdown of the interface types for the Shuttle/Payload Separation phase.

Table 4-3 Shuttle/Payload Separation Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
Device Status Data										✓
Shuttle Device Status Data										✓
Subsystem Commands										✓
Shuttle Commands										✓
Device Status Msgs									✓	
Shuttle Device Status Msgs									✓	
Subsystem Command Msgs					✓				✓	
Shuttle Command Msgs					✓					
Control Status Msgs									✓	
S/C Status Msgs							✓		✓	
Shuttle Status Msgs							✓		✓	
System Command Msgs					✓				✓	
S/C Status Display to User	✓		✓							
Shuttle Status Display to User	✓		✓							
Shuttle Command Req	✓		✓	✓						

4.3.2 EXPENDABLE LAUNCH VEHICLE MISSIONS

4.3.2.1 Spacecraft and Launch Vehicle Integration

This phase of launch operations includes integration of the spacecraft with the launch vehicle (LV). The spacecraft goes through a final checkout. Spacecraft-LV interfaces are tested and verified. Launch countdown dress rehearsals are done as well as launch sequence and separation sequence testing.

Refer to Figure 4-7 for the following discussion. Canned sequences, e.g., launch and payload separation, are usually loaded into the spacecraft pre-launch. When the tests are executed, telemetry generated by the launch vehicle and the spacecraft is received by the launch facility while on the ground (see 1, 4, and 2 in the figure). The launch facility separates the LV and spacecraft telemetry. A ground station or ground station simulator is used to test post-launch telemetry interfaces (see 5, 7, and 6 in the figure). The ground system's telemetry processor then extracts the spacecraft packets (see 3 in the figure). The ground system then routes the packets to the user (see 9 in the figure). While on the ground the spacecraft can receive directives through the launch facility (see 8 in the figure) for spacecraft checkout tests. The LV can also receive directives for separation sequence testing (see 11 in the figure). In some instances the LV is responsible for initiating the spacecraft separation sequence and this is tested (see 10 in the figure).

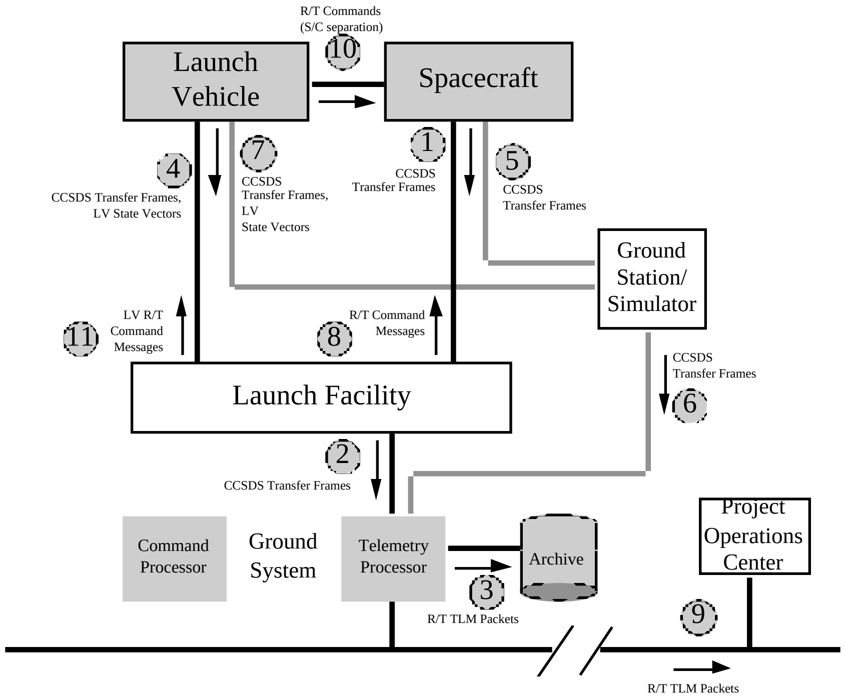

Figure 4-7 SuperMOCA Spacecraft and Launch Vehicle Integration

Refer to Figure 4-8 for the following discussion. This figure is an application of the interfaces in Figure 4-7 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The directives needed to perform the test are usually stored on board the spacecraft and LV pre-launch. Subsystem directives are sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the tester issue a summary report to the ground, via SCPS, upon execution of the test. Note that the ***Plan*** function is not used for this phase.

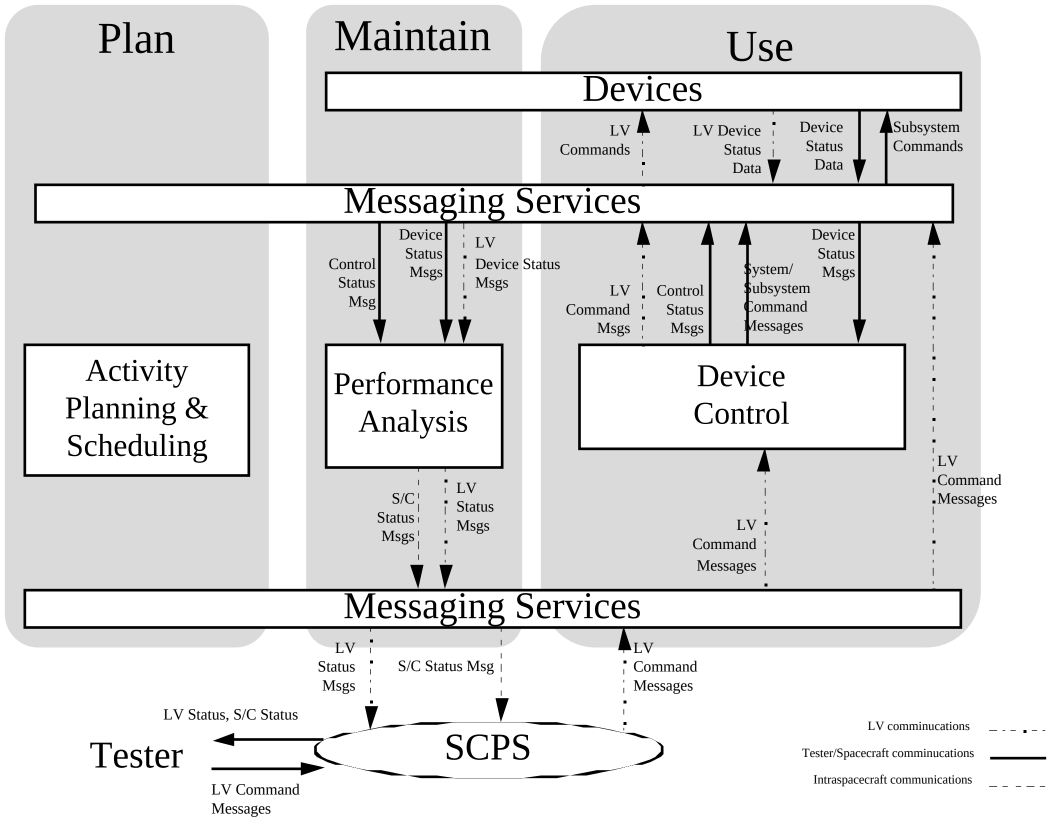

Figure 4-8 SuperMOCA Application of Spacecraft and Launch Vehicle Integration Interfaces

System directives in the stored command loads are used in order to set the spacecraft to a prerequisite state if needed for the test to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Table 4-4 below is a breakdown of the interface types for the Spacecraft and Launch Vehicle Integration phase.

Table 4-4 Spacecraft and Launch Vehicle Integration Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
LV Device Status Data										✓
Device Status Data										✓
Subsystem Command										✓
LV Commands										✓
Device Status Msgs									✓	
LV Device Status Msgs									✓	
Subsystem Command Msgs									✓	

	A	C	D	E	F	G	H	I	J	Internal
System Command Msgs									✓	
Control Status Msgs									✓	
LV Command Msgs							✓		✓	
S/C Status Msg							✓		✓	
LV Status Msg							✓		✓	
S/C Status Display to User	✓		✓							
LV Status Display to User	✓									
LV Command Req	✓		✓		✓					

4.3.2.2 Launch Pad Operations

Refer to Figure 4-9 for this discussion. During rollout to the launch pad, there is no standard capability to power up or monitor spacecraft elements. On the pad prior to launch, spacecraft systems may be monitored through the launch facility (see 1 and 2 in the figure) as well as launch vehicle telemetry (see 5 in the figure). After the launch vehicle is delivered to the launch pad a launch readiness verification test is conducted.

All elements of mission control are transferred to the mission control center at the project's designated center from the time the spacecraft has cleared the launch tower.

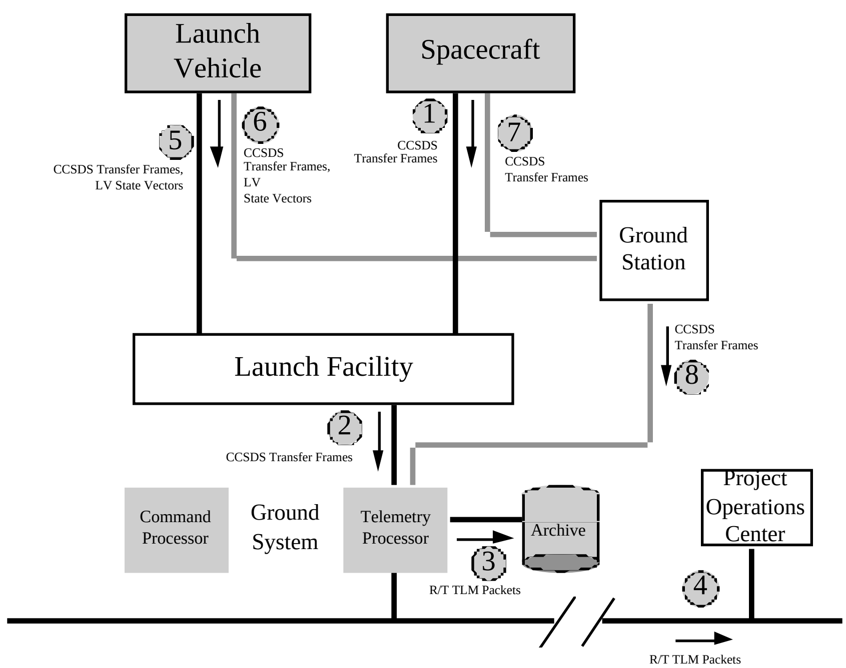

Figure 4-9 SuperMOCA Launch Vehicle Launch Pad Operations

After launch, telemetry is received by the launch facility tracking stations (and eventually by the ground stations, see 6 and 7 in the figure), processed by the ground system (see 8 and 3 in the figure), and received by the users (see 4 in the figure). LV state vectors are received by the launch facility for orbit injection determination (see 5 in the figure).

Refer to Figure 4-10 for the following discussion. This figure is an application of the interfaces in Figure 4-9 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. Devices on board the spacecraft are not being commanded during this phase and therefore only report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can issue a summary report to the ground, via SCPS. Note that the ***Plan*** function is not used for this phase.

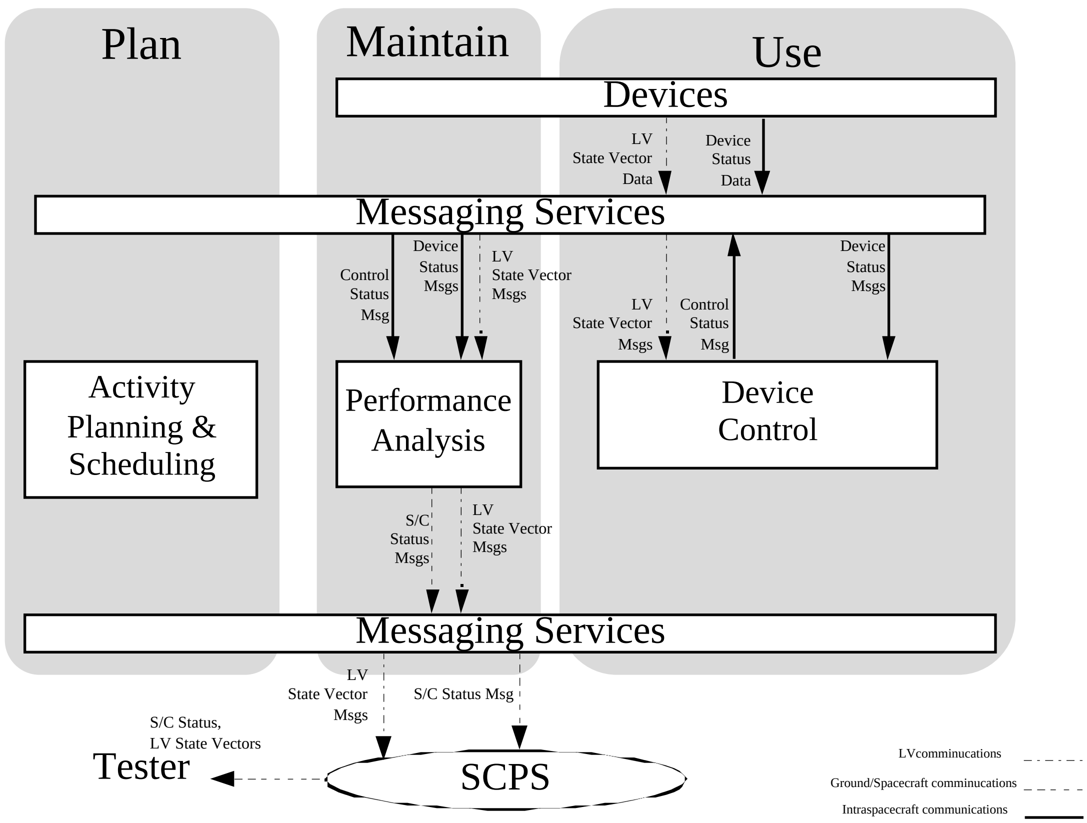

Figure 4-10 SuperMOCA Application of Launch Pad Operations Interfaces

Table 4-5 below is a breakdown of the interface types for the Launch Pad Operations phase.

Table 4-5 Launch Pad Operations Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
LV State Vector Data										✓
Device Status Data										✓
Device Status Msg									✓	
Control Status Msg									✓	
LV State Vector Msg							✓		✓	
S/C Status Msg							✓		✓	
S/C Status Display to User	✓		✓							
LV State Vector Display to User	✓		✓							

4.3.2.3 Spacecraft Separation

Refer to Figure 4-11 for this discussion. Spacecraft separation sequences, are loaded into the spacecraft pre-launch. When executed, telemetry generated by the LV and the spacecraft is received by the ground station (see 1, 2, and 11 in the figure). The ground system's telemetry processor extracts the spacecraft packets (see 3 and 4 in the figure) then routes the packets to the user (see 5 in the figure). If there is any spacecraft commanding, e.g., a go-separation directive (see 6, 7, and 10 in the figure) then the Project Operations Center uplinks directives through the ground station. LV commanding is also done through the ground station (see 7 and 8 in the figure). Often the LV's stored sequence issues the go-separation command to the spacecraft (see 9 in the figure).

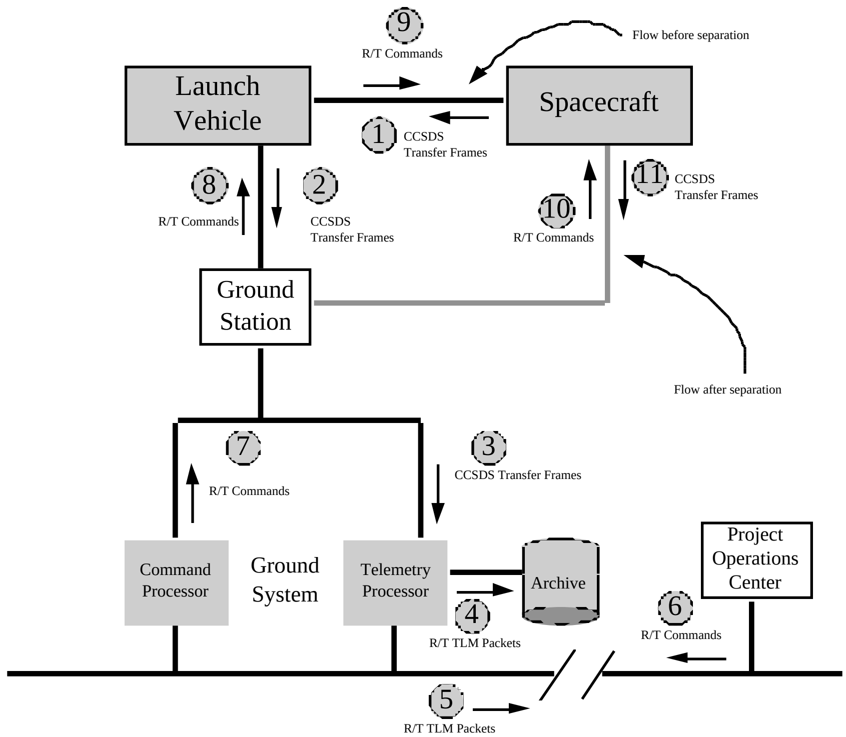

Figure 4-11 SuperMOCA Spacecraft/Launch Vehicle Separation

Refer to Figure 4-12 for the following discussion. This figure is an application of the interfaces in Figure 4-11 to the Plan, Use, Maintain SuperMOCA concept for an I&T system. The directives needed to perform spacecraft separation are loaded pre-launch in the spacecraft and optionally in the LV, during separation these directives are sent to the S/C Device Control function (***Use*** in the figure). The S/C Device Control function then computes and sends the actual commands to the various devices. The devices upon execution of these device commands report their status (e.g., state change information, and diagnostics) to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the user issue a summary report to the ground, via SCPS, upon execution of the separation. Note that the ***Plan*** function is not used for this phase.

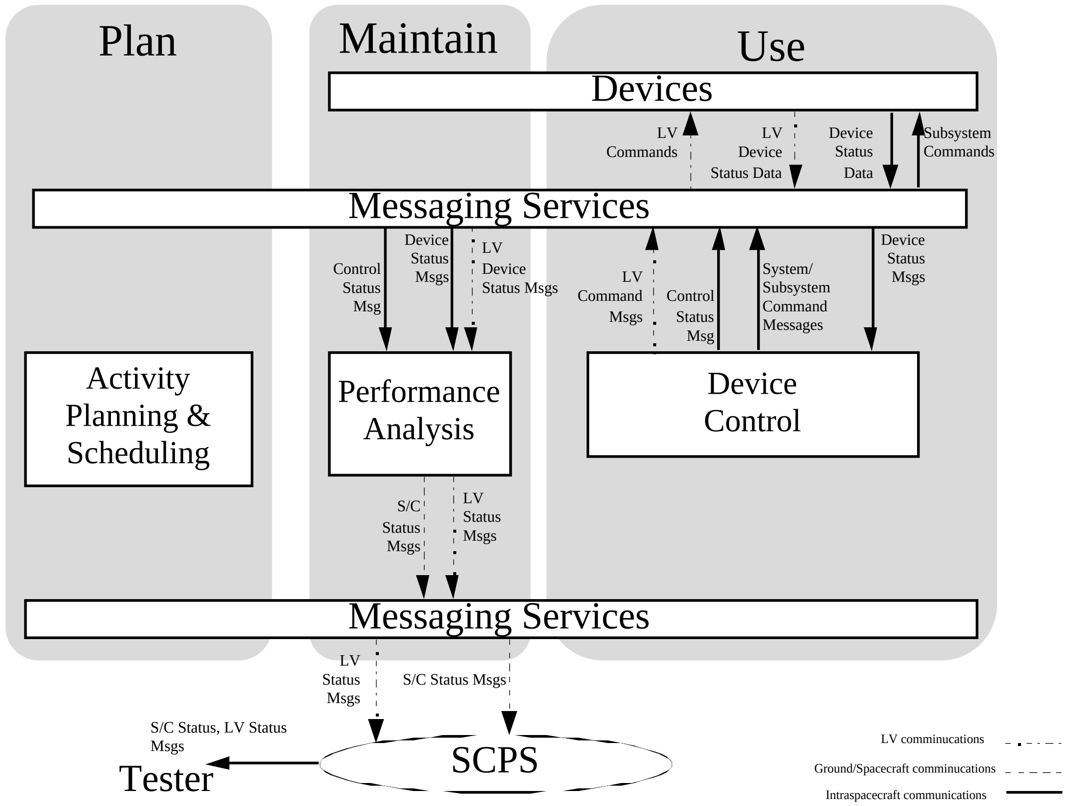

Figure 4-12 SuperMOCA Application of Spacecraft/Launch Vehicle Separation Interfaces

System directives in the stored command loads are used in order to set the spacecraft to a prerequisite state if needed for the separation to execute. These directives go to the S/C Device Control function (***Use*** in the figure) which then generates the appropriate commands to the individual devices.

Table 4-6 below is a breakdown of the interface types for the Spacecraft/Launch Vehicle Separation phase.

Table 4-6 Spacecraft/Launch Vehicle Separation Interfaces by Type

	A	C	D	E	F	G	H	I	J	Internal
LV Device Status Data										✓
Device Status Data										✓
Subsystem Commands										✓
LV Commands										✓
Device Status Msgs									✓	
LV Device Status Msgs									✓	
Subsystem Command Msgs					✓				✓	

	A	C	D	E	F	G	H	I	J	Internal
Control Status Msg									✓	
LV Status Msg							✓		✓	
S/C Status Msg							✓		✓	
System Command Msg					✓				✓	
S/C Status Display to User	✓		✓							
LV Status Display to User	✓		✓							

4.4 SUMMARY OF SUPERMOCA VIEW OF LAUNCH OPERATIONS

4.4.1 SHUTTLE MISSIONS

Refer to Figure 3-5 for the following discussion. Table 4-7 below summarizes the interface types that are found in the Launch Operations phase of a mission from the SuperMOCA perspective. It shows that most of the 57 interface types are type A (interfaces to/from the user), type D (interfaces to/from the Control Interface Language), and type J (to/from virtual devices onboard the spacecraft). This shows that the problem SuperMOCA addresses in this scenario is for the most part the monitor and control of onboard devices via the Control Interface Language.

Since the three most common types of interfaces are A, D, and J, it can be inferred that the **User Control Interface Language** interface, the **Control Interface Language SMS**, and **the SMS onboard Virtual Device** interface are very important to the success of SuperMOCA. This also means that issues like performance, functionality, and operability become critical at these junctures. Specifications for these three interface types (A, D, and J) must be given close attention and become at least for the Launch Operations phase of a mission crucial to the success of SuperMOCA.

Table 4-7 Summary of Interface Types for Launch Operations - Shuttle

	A	C	D	E	F	G	H	I	J	Internal
Number of Interfaces	**8**	**0**	**8**	**2**	**6**	**0**	**6**	**0**	**17**	**14**
% of Total Interfaces	**13%**	**0%**	**13%**	**3%**	**10%**	**0%**	**10%**	**0%**	**28%**	**23%**

4.4.2 EXPENDABLE LAUNCH VEHICLE MISSIONS

Refer to Figure 3-5 for the following discussion. Table 4-8 below summarizes the interface types that are found in the Launch Operations phase of a mission from the SuperMOCA perspective. It shows that most of the 52 interface types are type A (interfaces to/from the user) with type J (to/from virtual devices onboard the spacecraft) following closely. This shows that the problem SuperMOCA addresses in this scenario is for the most part the monitor and control of onboard devices via the SCPS stack.

Since the two most common types of interfaces are A, H, and J, it can be inferred that the **User Control Interface Language** interface, the **SMS SCPS stack**, and **the SMS onboard Virtual Device** interface are very important to the success of SuperMOCA. This also means that issues like performance, functionality, and operability become critical at these junctures. Specifications for these interface types (A, H, and J) must be given close attention and become at least for the I&T phase of a mission crucial to the success of SuperMOCA.

Table 4-8 Summary of Interface Types for Launch Operations - Expendable Launch Vehicle

	A	C	D	E	F	G	H	I	J	Internal
Number of Interfaces	**7**	**0**	**6**	**0**	**3**	**0**	**7**	**0**	**19**	**10**
% of Total Interfaces	**13%**	**0%**	**12%**	**0%**	**6%**	**0%**	**13%**	**0%**	**37%**	**19%**

5. MISSION OPERATIONS SCENARIOS

5.1 INTRODUCTION

This section presents a set of operational scenarios from the perspective of the space system user (e.g., scientist, engineering team member, mission planner). The mission components elements that are available to the user include the ground system, ground terminals, and the spacecraft. The operational scenarios are categorized by levels of spacecraft autonomy inherent in each scenario. Further, the scenarios examine how autonomy could be distributed between the SuperMOCA functional areas, see the SuperMOCA Architecture Document, and how standardized interfaces could improve mission operations.

5.2 SCENARIO 1 - HIGH LEVEL OF SPACECRAFT AUTONOMY

5.2.1 MISSION PHASE VIEWPOINT

After the spacecraft has been launched into orbit, achieves the proper orientation for deployments and initial acquisition has been completed, the next phases, orbital injection and checkout, begin with the spacecraft inserted into the proper orbit/trajectory and end with the initialization of the spacecraft (including payload) ready to execute the cruise or orbital portion of the mission. During this time, pre-planned and stored sequences are usually used to initialize the spacecraft for the cruise or orbital portion of the mission. The spacecraft operates in an autonomous mode with telemetry being transmitted. SuperMOCA as in the launch phase provides the messaging services on board the spacecraft and the protocols used in communications with the ground.

The science mission operations phase performs the scientific observations as outlined in the science/mission plan. The activities in this phase include orienting the spacecraft as needed for observations, monitoring system performance, managing faults, managing the movement of messages among the virtual devices, collecting and transmitting science data as messages, calibrating the instruments and processing and distributing science data to the investigators. SuperMOCA provides the mechanism that the science investigators and their instruments use to talk to each other. In addition, SuperMOCA provides the messaging services the spacecraft needs to provide overall spacecraft health and safety.

The maneuver phase is used to interrupt the normal mission operations phase to re-orient the spacecraft in a safe and reliable manner. The spacecraft's propulsion system and/or attitude maneuvers are initiated and then fired. When the spacecraft achieves its desired attitude, the spacecraft is checked out for health. Then, the spacecraft and its instruments are transitioned to the operational mode. SuperMOCA provides the messaging services used to safe subsystems on board the spacecraft, initiate and fire the propulsion system, return the spacecraft to the operating mode, record telemetry on board and return data to the ground.

5.2.2 SUPERMOCA FUNCTIONAL AREA VIEWPOINT[2]

The intent of this section is to provide a description of how a space mission that adheres to SuperMOCA could operate each of the functional areas depicted in the SuperMOCA Architecture Document (Orbit/Trajectory, Attitude/Pointing, Power, Thermal, Data Handling, System Executive) given a high level of autonomy present in the mission. Within each functional area is the hidden user, hidden in the sense that the user is the recipient of most of the monitor data that is generated by each functional area and the originator of most of the control data, but is not shown explicitly in each diagram.

5.2.2.1 Orbit/Trajectory Function

Figure 5-1 depicts a design and functional allocation between space and ground for the orbit/trajectory function. This design provides for on-board autonomous control of orbit maneuvers including low earth orbit mission measurement of spacecraft position and determination of an accurate time reference. Independent ground calibration of the orbit computations compares on-board spacecraft ephemeris with tracking data to provide the necessary backup and check on the spaceborne functions.

Refer to Figure 5-1 for the following discussion. This function usually starts with a decision either pre-launch as part of the mission design or post-launch as a result of an anomaly, analysis of spacecraft/instrument performance, or mission redesign to schedule an orbit trim maneuver or TCM (see A in figure). The spacecraft control center requests a series of tracking passes to obtain range and velocity data (see B in figure). The data is then analyzed and a desired trajectory adjustment is generated by project navigators (see C in figure). Current velocity and position data is uplinked to the spacecraft - or for LEO missions, the GPS receiver provides this data (see D in figure).

[2] The diagrams in this section were obtained from the GSFC MOCA document and modified for SuperMOCA purposes.

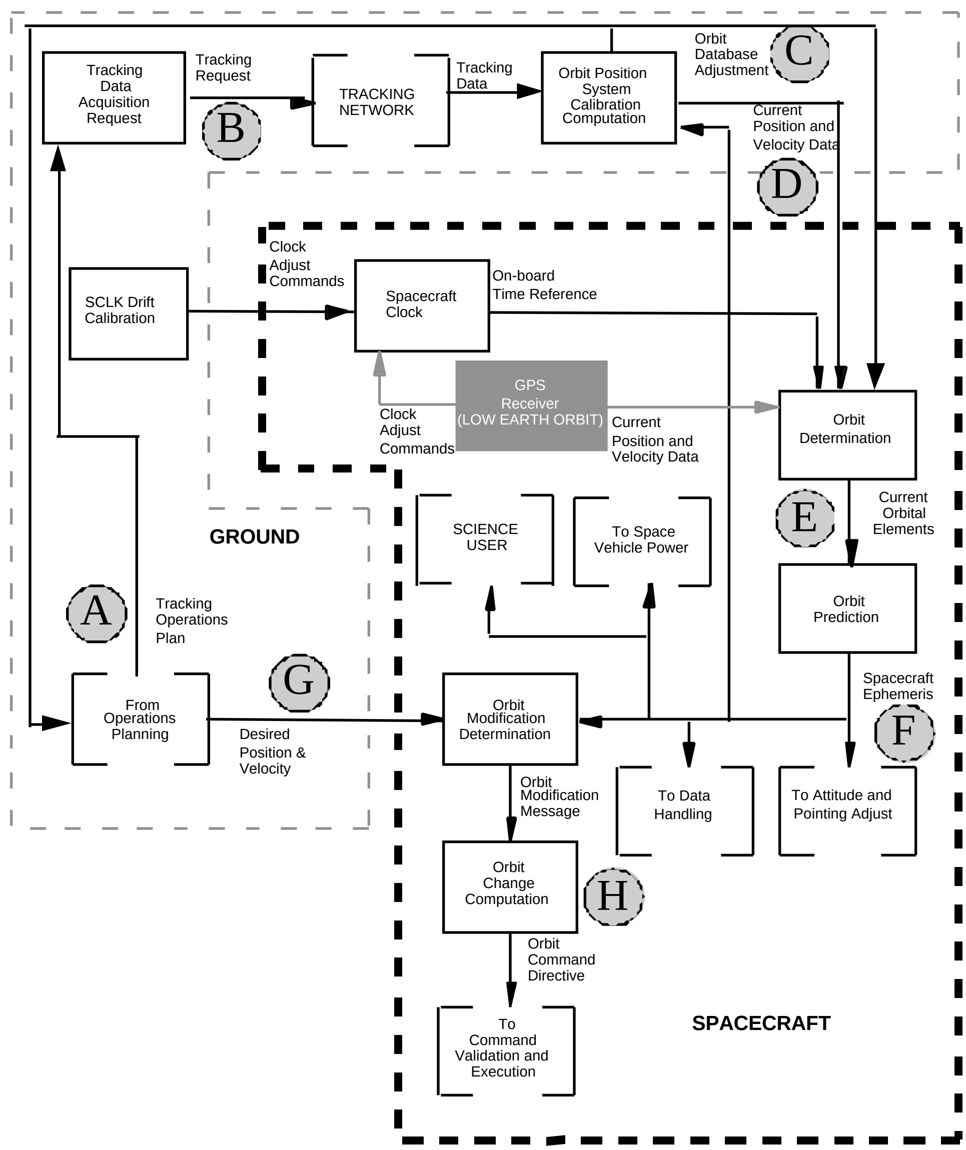

Figure 5-1 Functional Allocation between Space & Ground for the Orbit Determination Function

The Orbit Determination function on-board takes the position and velocity data and generates current orbital elements (see E in figure). Spacecraft ephemeris data is then generated and distributed to among others, the Orbit Modification function (see F in figure). The ground at the time of position and velocity data uplink also transmits the desired spacecraft ephemeris (see G in figure). The spacecraft then calculates the delta-V required (how long to fire the thrusters), the delta-V direction, and the epoch of the TCM (see H in figure). Time data is supplied by the spacecraft clock with updates (as a result of oscillator drift predicts) supplied by the ground. The ground can always direct the spacecraft to record the execution of the maneuver for playback at a later time for reconstruction. Also the ground can predict the maneuver parameters and compare them to the spacecraft generated parameters as a check against on board algorithms.

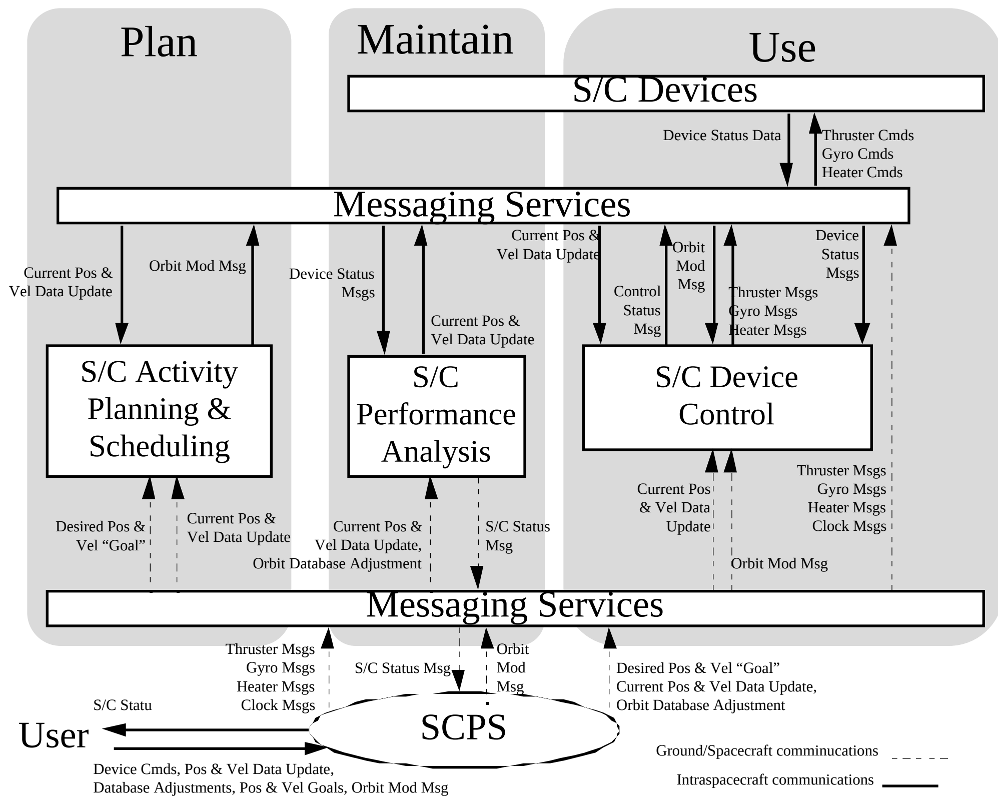

Figure 5-2 SuperMOCA application of Orbit Determination Interfaces on board the Spacecraft

Refer to Figure 5-2 for the following discussion. This figure is an application of the interfaces in Figure 5-1 to the Plan, Use, Maintain SuperMOCA concept on board the Spacecraft. The ground uplinks, via the SCPS protocol, necessary information as messages to the Activity Planning & Scheduling function (current position & velocity, desired position and velocity, and any S/C clock adjustment commands) for the S/C to calculate the maneuver parameters. The term that will be used to command an intelligent spacecraft to perform some action will be a *goal*. Goals primarily are intended to be processed by the *Plan* Function.

With this information plus other on-board supplied data (for example S/C time reference, on-board rules and constraints, and current S/C states), the Activity Planning & Scheduling function (***Plan*** in the figure) schedules a maneuver at the appropriate time and formats the data as a device message here called an Orbit Modification message. This

Orbit Modification message is sent to the Device Control function (***Use*** in the figure) which then calculates the epoch, the difference between the actual ephemeris and the desired ephemeris, and finally the maneuver parameters. The Device Control function then sends the actual commands to the devices (thrusters, heaters, valves). The devices upon execution of these device commands report the status to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the ground issue a summary report to the ground upon execution of the maneuver. The ground can alternately send the individual commands to the devices themselves, or it can send the Orbit Modification Message itself to the Device Controller.

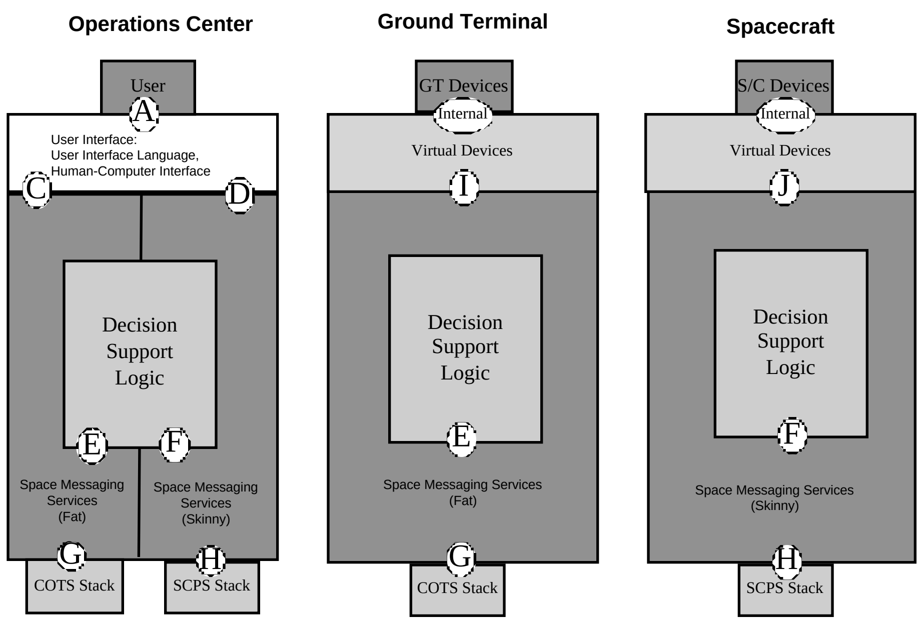

Figure 5-3 SuperMOCA Interface Types

Figure 5-3 is a depiction of the 10 different types of interfaces found in SuperMOCA compliant implementations. This figure will be used to identify the types of interfaces found in each functional area. This information will be used to identify what capabilities are needed for the space messaging system, and in turn will be used to write the specifications for the messaging system. Table 5-1 below is a breakdown of the interface types for the Orbit Determination functional area.

Table 5-1 Orbit Modification Interfaces by Interface Type

Interface Type ⟶	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Desired Pos/Vel "Goal" Req	✓		✓		✓				
Desired Pos/Vel "Goal"					✓		✓		
Desired Pos/Vel Data Update Req	✓		✓		✓				

Interface Type →	A	C	D	E	F	G	H	I	J
Desired Pos/Vel Data Update					✓		✓		
Orbit Mod Msg					✓		✓		
Orbit Database Adjustment Req	✓		✓		✓				
Orbit Database Adjustment									
Device Msg Requests	✓		✓		✓				
Device Msgs							✓		✓
Device Status Reports	**Internal**								
Device Cmds	**Internal**								
Current Pos/Vel Data Update Req	✓		✓		✓				
Current Pos/Vel Data Update					✓		✓		✓
Device Status Msg									✓
Control Status Msg									✓

5.2.2.2 Attitude/Pointing Function

Figure 5-4 shows the SuperMOCA attitude/pointing function. This function controls the space vehicle, keeping it stable and pointed in the proper direction. As needed, it will slew or rotate the vehicle about its center of mass, using a reference that may be celestial, earth pointing, or simply a measurement on the vehicle of inertial motion. It will also develop attitude data that is used to determine the current attitude and predict the future attitude. Routine attitude control (that is, attitude hold), because of its real-time character, is traditionally performed on the space vehicle. Major attitude maneuvers are driven by spacecraft operations and may be controlled on-board the spacecraft or from the ground. Consistent with increased spacecraft autonomy, the design depicted here reflects control of attitude maneuvers being performed on-board the spacecraft.

Refer to Figure 5-4 for the following discussion. The ground provides the spacecraft with pointing and path constraints that were generated pre-launch as part of the mission design or as a result of post-launch analysis of spacecraft/instrument performance. The ground also either pre-launch or as a result of post-launch analysis, provides the spacecraft with a set of references to use in computation of attitude/orientation vectors - these references could be star catalogues or yaw/pitch/roll deadband limits for example (see A in figure). The spacecraft measures its attitude and generates attitude vectors (see B in figure). This information is distributed on board the spacecraft.

The spacecraft can determine in several ways if an attitude change maneuver needs to be executed. The power subsystem can request a change of attitude, for example, if the solar panels need to be oriented in some way relative to the sun if power subsystem conditions have been met (see C in figure). The ground can direct the spacecraft to attain some special attitude as a result of instrument/spacecraft performance, science observation targets, or an anomaly (see D in figure). Or as a result of vector addition between the current attitude and the attitude hold vectors, the spacecraft determines that the error is great enough that an attitude maneuver is necessary (see E in figure). Time data is supplied by the spacecraft clock with updates (as a result of oscillator drift predicts) supplied by the ground. The ground can always direct the spacecraft to record the execution of the maneuver for playback at a later time.

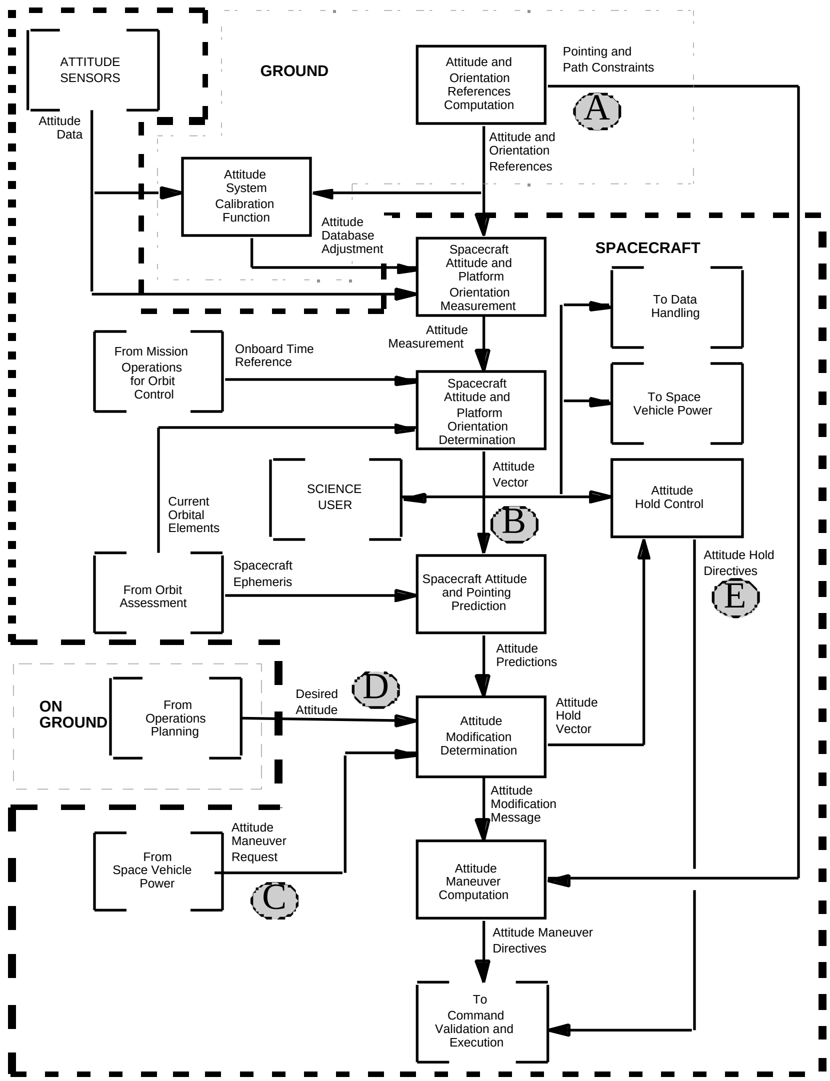

Figure 5-4 Functional Allocation between Space & Ground for the Attitude/Pointing Function

Also the ground can predict the maneuver parameters and compare them to the spacecraft generated parameters as a check against on board algorithms.

Refer to Figure 5-5 for the following discussion. This figure is an application of the interfaces in Figure 5-4 to the Plan, Use, Maintain SuperMOCA concept on board the Spacecraft. The ground uplinks, via the SCPS protocol, necessary information as messages to the S/C Performance Analysis and S/C Device Control functions (pointing constraints, attitude reference changes, calibration updates, and any S/C clock adjustment commands) for the S/C to maintain the appropriate S/C orientation. Alternately, the ground can send a reorientation goal to the spacecraft.

With this information plus other on-board supplied data (for example S/C time reference, on-board rules and constraints, current S/C states, predicted attitude vectors, and attitude hold vectors), the S/C Performance Analysis function (***Maintain*** in the figure) determines if an attitude modification maneuver is required. If so, it sends out a Desired Attitude Request to the S/C Activity Planning function (***Plan*** in the figure). This function then schedules a maneuver at the appropriate time and formats the data as a device message here called an Attitude Modification message. This Attitude Modification message is sent to the Device Control function (***Use*** in the figure) which then calculates the epoch, the difference between the actual attitude vector and the desired attitude vector, and finally the attitude change parameters. The Device Control function then sends the actual commands to the devices (thrusters, heaters, valves). The devices upon execution of these device commands report the status to the Performance Analysis function (***Maintain*** in the figure) which stores the information received from the devices and can if directed by the ground issue a summary report to the ground upon execution of the maneuver.

Refer to Figure 5-3 for this discussion. This figure is a depiction of the 10 different types of interfaces found in SuperMOCA compliant implementations. This figure will be used to identify the types of interfaces found in each functional area. This information will be used to identify what capabilities are needed for the space messaging system, and in turn will be used to write the specifications for the messaging system. Table 5-2 is a breakdown of the interface types for the Attitude/Pointing functional area.

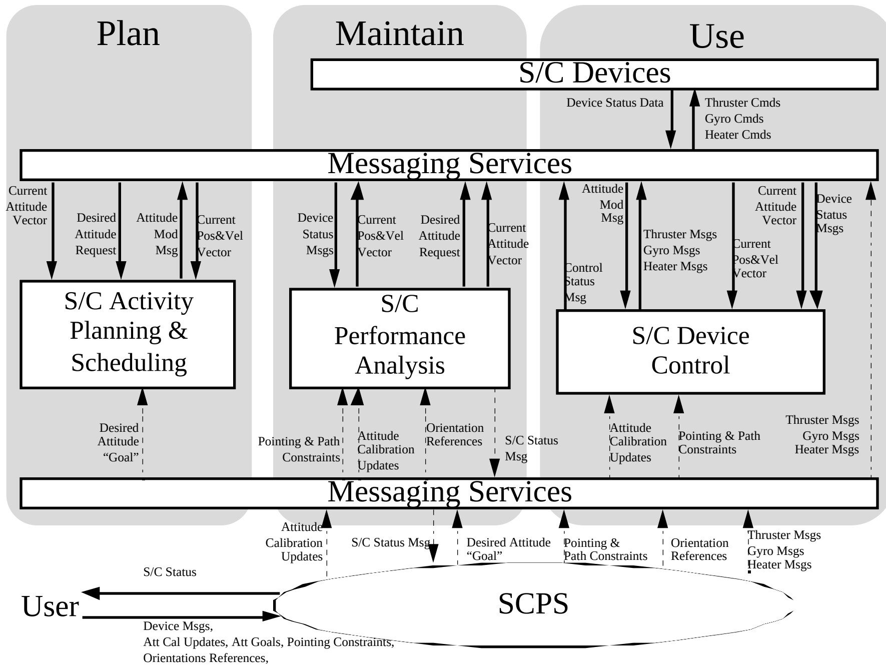

Figure 5-5 SuperMOCA application of Attitude Pointing Interfaces on board the Spacecraft

Table 5-2 Attitude/Pointing Interfaces by Type

Interface Type →	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Desired Attitude “Goal” Req	✓		✓		✓				
Desired Attitude “Goal”					✓		✓		
Attitude Calibration Updates Req	✓		✓		✓				
Attitude Calibration Updates					✓		✓		
Pointing/Path Constraints Req	✓		✓		✓				
Pointing/Path Constraints					✓		✓		
Orientation References Req	✓		✓		✓				
Orientation References					✓		✓		
Attitude Mod Msg					✓				
Device Msg Requests	✓		✓		✓				
Device Msgs					✓		✓		✓
Device Status Reports	**Internal**								
Device Cmds	**Internal**								
Current Pos/Vel Vector					✓				

Interface Type ⟶	A	C	D	E	F	G	H	I	J
Current Attitude Vector					✓				
Desired Attitude Request					✓				
Device Status Msg									✓
Control Status Msg									✓

5.2.2.3 Space Vehicle Power Function

The design for a SuperMOCA-compliant space vehicle power function is identical to Figure 5-6. This design is fully autonomous; all functionality is allocated to the space segment. Note that fully autonomous spacecraft power functions are currently being flown so the disparity between a SuperMOCA-compliant mission and a current generation mission is small in this area. The ground segment only monitors the actions of the space vehicle for emergency and maintenance purposes. Earth orbiting spacecraft electrical systems usually consist of solar cells and battery storage. Deep space or long-life missions may use radioisotope thermal generators (RTGs) as a source of power. Both approaches require monitoring and control of loads, power transients, and power system temperature. Solar-based systems also require orientation of solar arrays and management of battery charging.

Refer to Figure 5-6 for the following discussion. On-board software uses spacecraft ephemeris and attitude to calculate the pointing angles for the solar array (see A in the figure). Depending on the current load, battery state of charge, array temperature, and other factors, the on-board software may wish to constrain the output to a less-than-maximum value (see B in figure) by re-pointing the solar arrays, using shunts, or switching sections off-line. If so, the on-board software will adjust the arrays for lower output (see C in figure).

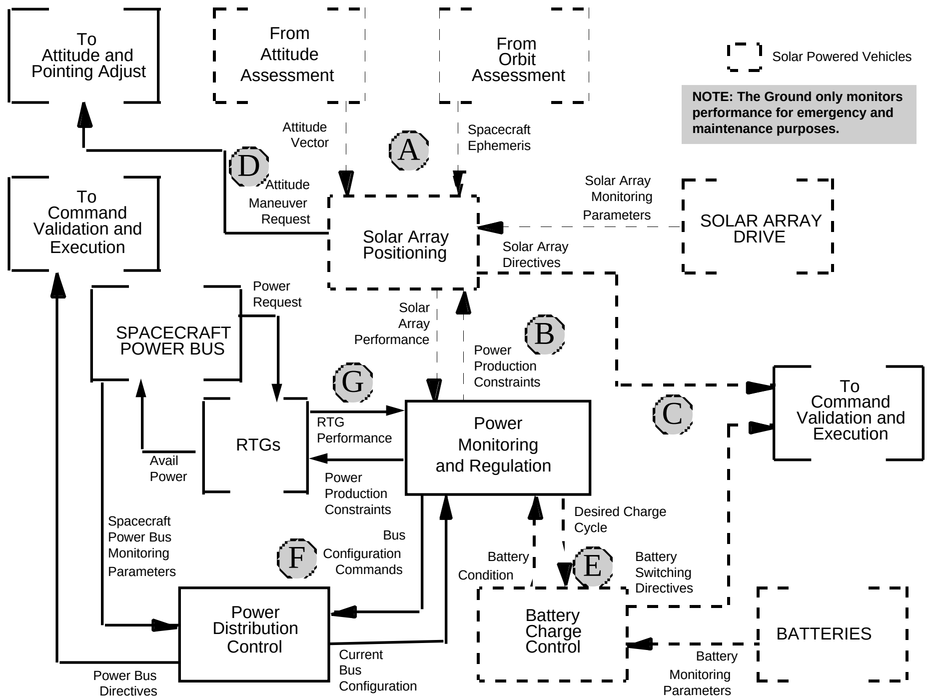

Figure 5-6 Functional Allocation between Space and Ground for the Power Function

Attitude maneuvers may be necessary periodically to allow proper positioning of the arrays. In this case, on-board software sends a request to the attitude/pointing system to make the appropriate attitude change (see D in figure). The spacecraft also monitors solar array or RTG performance (notably voltage, current, and temperature), making adjustment as necessary. Summaries of this solar array performance data are passed to the power monitoring and regulation function to aid in developing power management strategies.

The power monitoring and regulation function provides the executive control of the space vehicle power function. This function is responsible for high-level power management (e.g., battery/solar array load balancing), and high-level spacecraft power bus control (e.g., load shedding and bus voltage and current). For example, a solar array powered mission may experience a seasonal condition of full sun and low power needs. During this period, periodic deep-cycle discharge of the batteries would be required for their maintenance. The power monitoring and regulation function might modify solar array positioning to lower its output (see B in figure), command the power distribution control to switch on extra loads, such as heaters (see F in figure), and command the battery charge control function to its lowest rate of charge (see E in figure). Summaries of power source performance data (e.g., state of charge) are passed to the power monitoring and regulation function to assist in power management (see G in figure).

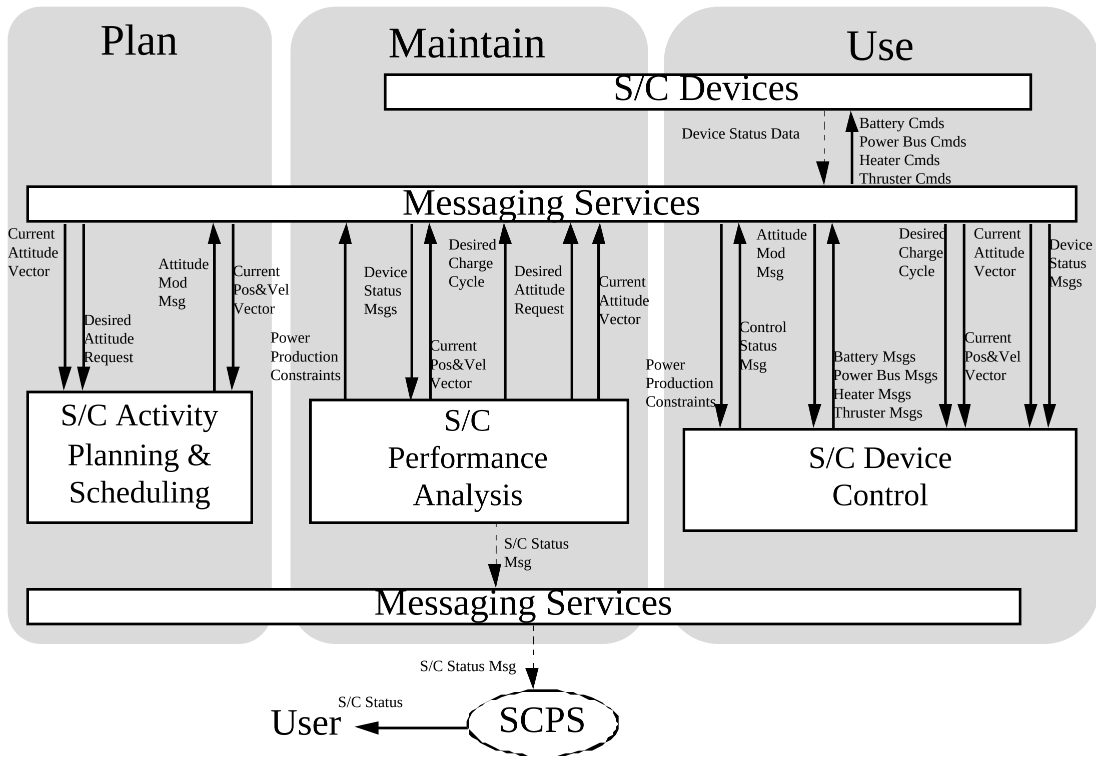

Figure 5-7 SuperMOCA application of Power Interfaces on board the Spacecraft

The power distribution control function manages the lower-level aspects of spacecraft power bus control. These include switching of loads (in response to commands from the power monitoring and regulation function), managing over-current or over-voltage conditions, and load sequencing to manage transients.

Refer to Figure 5-7 for the following discussion. This figure is an application of the interfaces in Figure 5-6 to the Plan, Use, Maintain SuperMOCA concept on board the Spacecraft. The ground monitors S/C performance in this area for emergency and maintenance purposes only. Thus the power function on-board is an autonomous process for the most part.

For spacecraft with solar arrays, the Device Control function (***Use*** in the figure) can detect if the spacecraft needs to be re-oriented to satisfy power production constraints/requirements. The Performance Analysis function (***Maintain*** in the figure) then issues a Desired Attitude Request to the Activity Planning & Scheduling function(***Plan*** in the figure). The *Plan* function then schedules an Attitude Modification message at the appropriate time. This Attitude Modification message is sent to the Device Control function which then calculates the epoch, the difference between the actual attitude vector and the desired attitude vector, and finally the attitude change parameters. The Device Control function then sends the actual commands to the devices (thrusters, heaters, valves). The devices upon execution of these commands report the status to the Performance Analysis function which stores the information received from the devices and can if directed by the ground issue a summary report to the ground upon execution of the maneuver.

The Performance Analysis function also determines if a desired charge cycle is called for based on device status messages (e.g. low power needs). The *Maintain* function then sends a message to the *Use* function for the battery controllers to use the lowest rate of charge. The Performance Analysis function also determines power bus configuration and power source output based on device status reports. It generates a new set of power production constraints which are sent to the Device Control function which is tasked to compute the appropriate device messages (battery, power bus, and power switches for example). The ground can alternately uplink “goals” to the Planning function and/or device messages to the Device Control function in the case of an anomaly or emergency.

Refer to Figure 5-3 for this discussion. This figure is a depiction of the 10 different types of interfaces found in SuperMOCA compliant implementations. This figure will be used to identify the types of interfaces found in each functional area. This information will be used to identify what capabilities are needed for the space messaging system, and in turn will be used to write the specifications for the messaging system. Table 5-3 below is a breakdown of the interface types for the Power functional area.

Table 5-3 Power Interfaces by Type

Interface Type ⟶	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Current Pos/Vel Vector					✓				
Attitude Mod Msg					✓				
Device Msgs					✓				✓
Device Status Reports	**Internal**								
Device Cmds	**Internal**								
Current Attitude Vector					✓				
Desired Attitude Request					✓				
Desired Charge Cycle					✓				
Power Production Constraints					✓				
Device Status Msg									✓
Control Status Msg									✓

5.2.2.4 Space Vehicle Thermal Function

The thermal management function, Figure 5-8, helps to ensure the performance, and life of the spacecraft and science instruments by maintaining the temperature of spacecraft components within operational tolerances. The activities of the thermal management function are closely related to the actions of the space vehicle power function. This design is fully autonomous; all functionality is allocated to the space segment (in anomalous conditions, the ground can take on the functions of the thermal management function). Note that fully autonomous spacecraft thermal management functions are currently being flown so the disparity between a SuperMOCA-compliant mission and a current generation mission is small in this area. The ground segment only monitors the actions of the space vehicle for emergency and maintenance purposes.

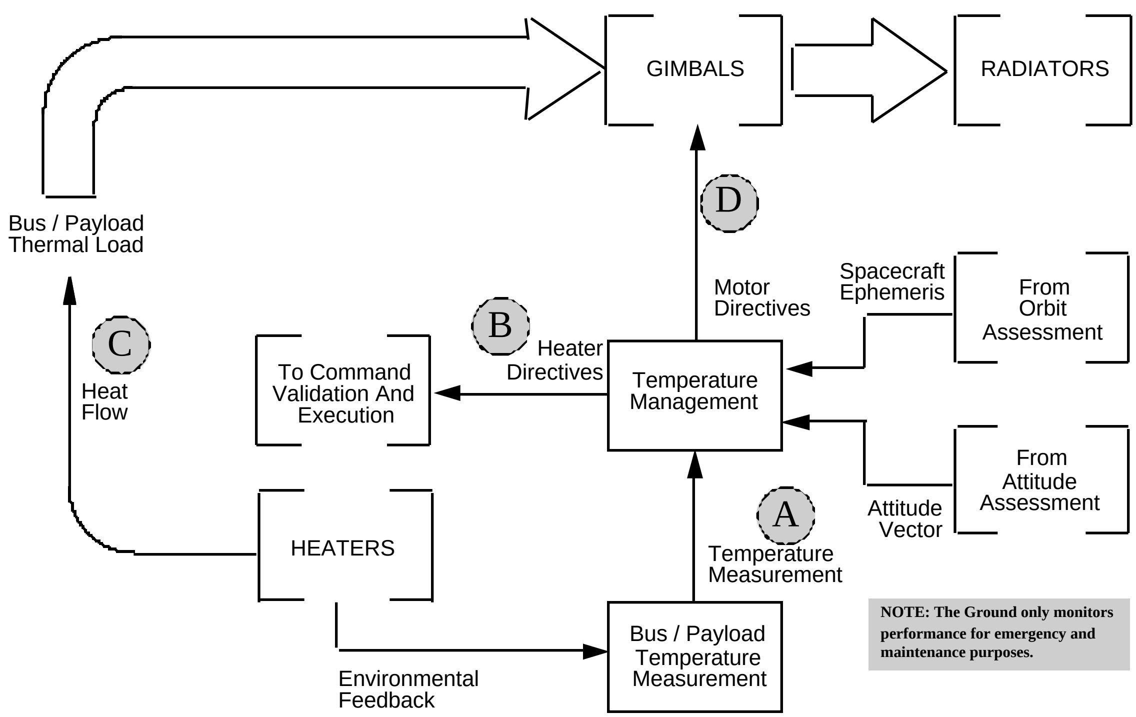

Figure 5-8 Functional Allocation between Space and Ground for the Thermal Function

Refer to Figure 5-8 for the following discussion. Thermal subsystems rely heavily on both passive and active thermal control designs. Insulation blankets, surface coatings, and thermal isolators are often used to temperature-stabilize components for low-earth and elliptical orbiting satellites. Deep space spacecraft sometimes may be slowly rotated to help maintain thermal stability, either continuously or to an attitude in which the sun's radiation is blocked by large structures on-board such as a high gain antenna. Active control systems also help to maintain thermal stability by monitoring the temperature of critical components (see A in the figure) and if needed activate heaters that keep critical components from becoming too cold (see B in the figure). Activation may occur through a thermostatic heater, or by a controller that regulates heater power. This auxiliary heat load is then dissipated by the thermal radiators (see C in the figure). An active radiator thermal management subsystem may also have gimbals to orient the radiator to maintain an acceptable temperature margin. In these instances, motor commands may result from a combination of spacecraft ephemeris and attitude information as well as from temperature measurements (see D in the figure).

Temperature data is monitored by the ground to ensure that spacecraft component functionality and performance is achieved, and to validate and correlate thermal math models. This monitoring also supports backup ground control of the Spacecraft's Thermal Control subsystem in the case of subsystem failure.

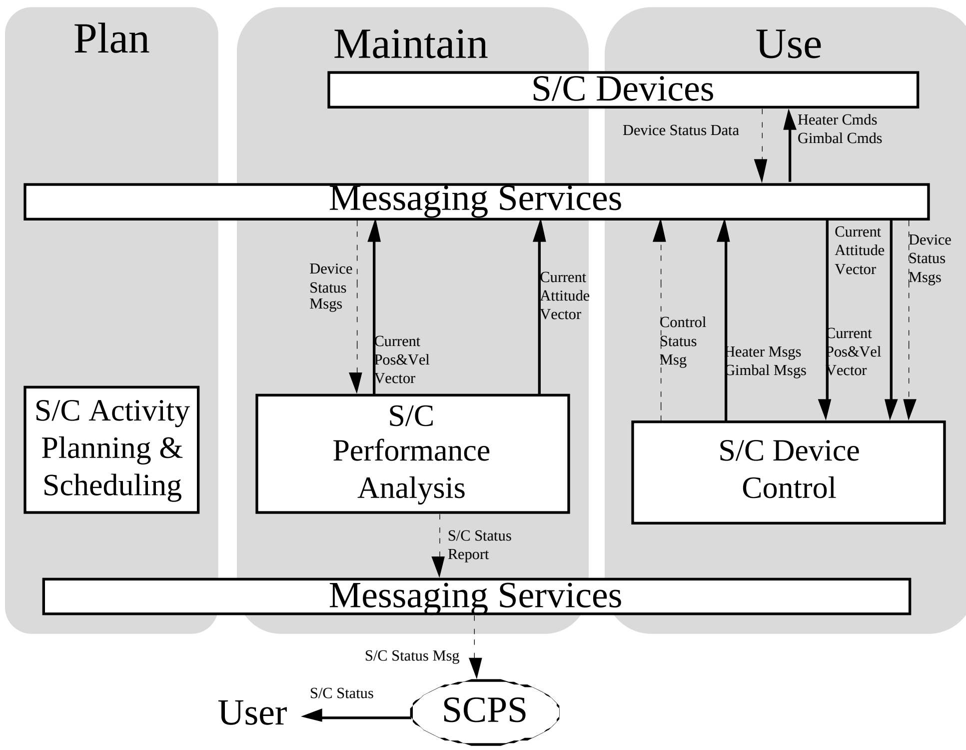

Figure 5-9 SuperMOCA Application of Thermal Interfaces on board the Spacecraft

Refer to Figure 5-9 for the following discussion. The ground is basically performing monitoring functions only for anomaly and maintenance purposes. This function is mostly autonomous. The Device Control function (***Use*** in the figure), receives status data from the thermal subsystem devices on board the spacecraft - temperature measurements and heater status. These data are used to determine if thermal radiators need to be reoriented to dissipate the appropriate amount of hear, or if heaters need to be turned either on or off. The ground can alternately send messages to individual devices in case of an anomaly or emergency. The ground can also command the spacecraft to change attitude to maintain appropriate thermal margins.

Refer to Figure 5-3 for the following discussion. This figure is a depiction of the 10 different types of interfaces found in SuperMOCA compliant implementations. This figure will be used to identify the types of interfaces found in each functional area. This information will be used to identify what capabilities are needed for the space messaging system, and in turn will be used to write the specifications for the messaging system. Table 5-4 below is a breakdown of the interface types for the Thermal functional area.

Table 5-4 Thermal Interfaces by Type

Interface Type →	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Current Pos/Vel Vector					✓				
Device Msgs					✓				✓
Device Status Reports	**Internal**								
Device Cmds	**Internal**								
Current Attitude Vector					✓				
Device Status Msg					✓				✓
Control Status Msg					✓				✓

5.2.2.5 Data Handling Function

The SuperMOCA Architecture Document described the end-to-end communications concept that underlies the SuperMOCA space-ground interface. This concept is based on CCSDS and the OSI network layers, as implemented in SCPS. As a result of this concept, applications on the ground and in the spacecraft can communicate in a peer-to-peer fashion.

The approach to data handling utilizes file-based data transfer schemes. This is true for both “stored” data, as well as “real-time” data and command uplinks. The interface to the application looks the same in all three cases. That is, as real-time instrument data is written to its storage “file”, in reality, it is immediately transferred to the ground. Non real-time data queues up in its file for later transmission to the ground. In SuperMOCA, three different modes of communication between space and ground are available: real-time (for “911” messages), next available opportunity (“pager” communications), and normal scheduled communications. Scheduled communications allow the contact to be planned in advance. The real-time and next available opportunity communications modes are demand access services.

5.2.2.5.1 Demand Access Service for Deep Space Vehicles

The current thinking is to utilize a “beacon” mode of operations where routine engineering downlink would be virtually eliminated. Spacecraft would continuously transmit a beacon tone as a subcarrier frequency. There would be four beacon tones.

Table 5-5 Four Beacon Tone Demand Access Descriptions

Tones	Meaning
Red	Mission is in jeopardy (“911 service”)
Orange	Track within a certain time (“pager service”)
Yellow	Track when convenient (“pager service”)
Green	No tracking required

The spacecraft automation environment that would utilize this mode of operations would most likely include a self or adaptive commanding capability, an adaptive science/engineering data acquisition capability, onboard fault protection that would allow the spacecraft to survive weeks without ground contact, and the ability to create “intelligent” summaries of engineering data.

The Red and Green tones are self describing. The Orange tone would mean for example that if tracking is not carried out within a certain amount of time (each project would have to define this duration), data will be lost, the mission will be in jeopardy, or the spacecraft will be in an idle state. The Yellow tone would mean for example that tracking should be done when convenient because some “interesting” data has been acquired, some routine calibration/maintenance operation needs to be carried out, or an unexpected event occurred on board that was corrected by fault protection.

Beacon tones are urgency-based requests for ground action and do not represent directly the state of the spacecraft (tracking would be required to determine the spacecraft state). Projects would have the flexibility to define the meaning of the tones as a function of mission phase. These tones would be subcarrier frequencies therefore no telemetry would be downlinked, and the signal-to-noise ratio would be lower than telemetry SNR recovery threshold. Routine ground monitoring could be accomplished with less equipment (no telemetry detection required), and with less accurate antenna pointing (this also means that a wider limit cycle on-board could be utilized requiring less attitude thruster cycling and therefore a savings in propellant).

An optional one tone on/off scheme could be implemented in which no tone means “everything is ok” while the presence of a tone would mean “emergency”.

5.2.2.5.2 Demand Access Service for Earth Orbiting Vehicles

The real-time service would make use of the TDRSS[3] Multiple Access (MA) capability using an S-band omni antenna. Except for a small outage area over the Indian Ocean, this approach would permit worldwide access to immediate (albeit low data rate) communications without the need for opportunity planning. Because of the operational characteristics of TDRSS MA service and the use of an omni antenna, real-time 911 service (the Red tone in Table 5-5 above) processing can bypass the planning-related

[3] Tracking and Data Relay Satellite System

elements of data handling: communications node ephemeris computation, communication opportunity computation, and communications asset planning and acquisition.

On the other hand, next available opportunity communications (the Yellow and Orange tones in Table 5-5 above) require planning for the contact “on the fly”. In this case, and for scheduled communications, the communications node ephemeris computation module pre-calculates the ephemerides of the potential communications nodes (ground stations and relay satellites) that can be involved in a particular communication session. This information, together with the spacecraft attitude and ephemeris, is used by the communications opportunity computation module to select a suitable communications path.

5.2.2.5.3 Data Handling Functional Allocation

Refer to Figure 5-10 for the following discussion. In allocating this functionality between space and ground, each of the modules (except the communications node ephemeris computation) has been bisected into a space-based element and a ground-based element. This is reasonable in that, for example, pointing the spacecraft antenna is functionally similar to pointing a ground station antenna. The interface to assets of the tracking network, however, is substantially different from the interface to the spacecraft antenna. As a result, some of the internal activities will be different.

Both Earth orbiting vehicles and deep space missions are addressed here. At one extreme, an experiment may require near real-time control, with control and relay of payload data through active links. At the other extreme data can be collected autonomously for long periods of time, stored, and relayed at specified times through the communication network to the operations center.

The data synchronization management function is responsible for determining when communications should be initiated, for example, immediate action when the spacecraft wants to transfer payload data, or when the flight team wants to uplink commands (see As in the figure). The function makes this determination both by examining the priority of queued communications traffic and on the receipt of a payload data transfer request from an instrument or from the flight team. This function triggers the communication planning and acquisition function to begin its process of establishing the physical communication link between space and ground (see B in the figure) if the request came from the ground. If the request came from a subsystem on board an earth orbiting spacecraft, then the data synchronization management function triggers antenna selection and pointing to establish a space-ground link (see C in the figure). If the spacecraft is an interplanetary vehicle, then there is no antenna selection (nominally) or computation needed for communicating with one of the TDRSSs, only the initialization and energizing of the current communications antenna is required.

For low Earth orbiting vehicles, TDRSS contacts schedule and ephemerides are used by the on-board communications opportunity computation to control the transponder modes and transponder on/off times.

The process for pointing the High Gain Antennas (HGAs) at the scheduled TDRSS spacecraft, and controlling the handover from one on-board HGA to the other is also computed and controlled by the antenna selection and pointing computation (see C in the figure). Using the attitude information from the on-board attitude / pointing subsystem, the spacecraft ephemeris from the on-board orbit / trajectory subsystem, and the ephemeris of the TDRSS spacecraft (see H in the figure), this function computes the required pointing angles and pointing commands for the HGA, accounting for obstructions of the antenna views, etc. It computes the handover times and commands from one HGA to the other, and executes all these commands according to the TDRSS contacts schedule. Similar functions exist on the ground to manage ground communications assets.

The peer-to-peer communications capability of SuperMOCA can be thought of as a wide area network. Since communications between space and ground occurs intermittently, network traffic queues up on both sides, waiting for the next connection. With the link established, the data synchronization management function manages the exchange of this message traffic, synchronizing the on-board and ground databases, receiving commands and data uploads, and passing spacecraft and payload data to the ground.

When the data synchronization management function determines that a communications link should be established between space and ground, the communications opportunity computation function acts as a router, using the ephemerides of the communication nodes (see D in the figure), together with the spacecraft attitude and ephemeris (see E in the figure), to select a suitable communications path.

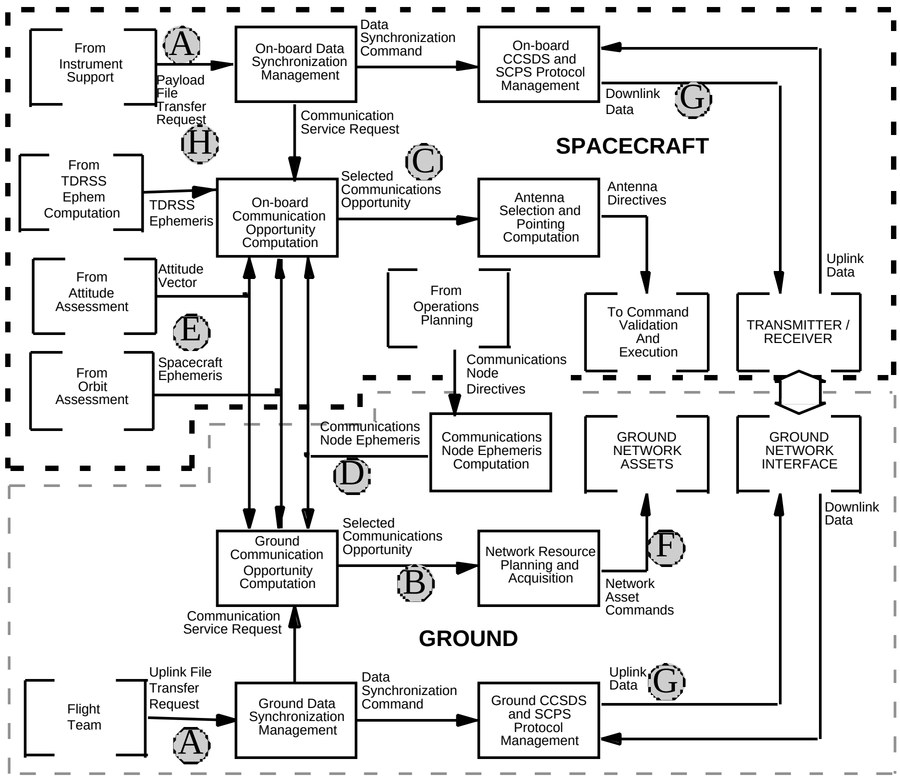

Figure 5-10 Functional Allocation between Space and Ground for the Data Handling Function

After the communications opportunity computation function has selected the communication path, the communication planning and acquisition function establishes the physical geometry of the communications link, acquires the needed communications resources, ground station, antenna, etc., and sends appropriate configuration commands to the communication assets, such as antenna pointing angles (see F in figure). At the conclusion of this activity, the communications link has been physically established.

With the physical link established, the CCSDS and SCPS protocols handle the actual exchange of the data using the SCPS file transfer protocol and the packetized data transfer process of SCPS to make efficient use of the communications bandwidth. The on-board and ground protocol management modules (see G in the figure) perform the standard CCSDS functions of generating, transmitting and receiving, and error correcting the CCSDS Virtual Channels and packets. These components control the on-board and ground RF communications functions. In addition, SCPS assures correct transmission of commands, tables, and data within the spacecraft and from the ground to the spacecraft (The Transport Layer protocol would add the feature of reliable data delivery for both uplink and downlink).

Refer to Figure 5-11 for the following discussion. The Device Control function (***Use*** in the figure) receives file transfer requests either from the ground or from one of the devices on board the spacecraft. The Device Control function then issues a

Communications Service Request to the Performance Analysis function (***Maintain*** in the figure) which after computations that might require the position and attitude of the spacecraft and the position of external communications nodes (TDRSS for low Earth orbiting vehicles for example) are made and Data Synchronization messages are sent to the Device Control for management of the queued data. Other messages that are sent include information regarding the downlink path chosen (both on-board and external). The Device Control function then sends messages to the individual device drivers which then reformat the messages to the actual commands that the devices act upon. The devices send the raw data to their individual device drivers (or virtual devices), messages are then created which encapsulate the data, and SCPS using its File Transfer Protocol is then responsible for the data delivery to the ground.

The user also might send device control messages to the ground terminal to configure the system for the receipt of data. SCPS is not the stack in this case, the commercial ground network internet protocols would be used for this message traffic.

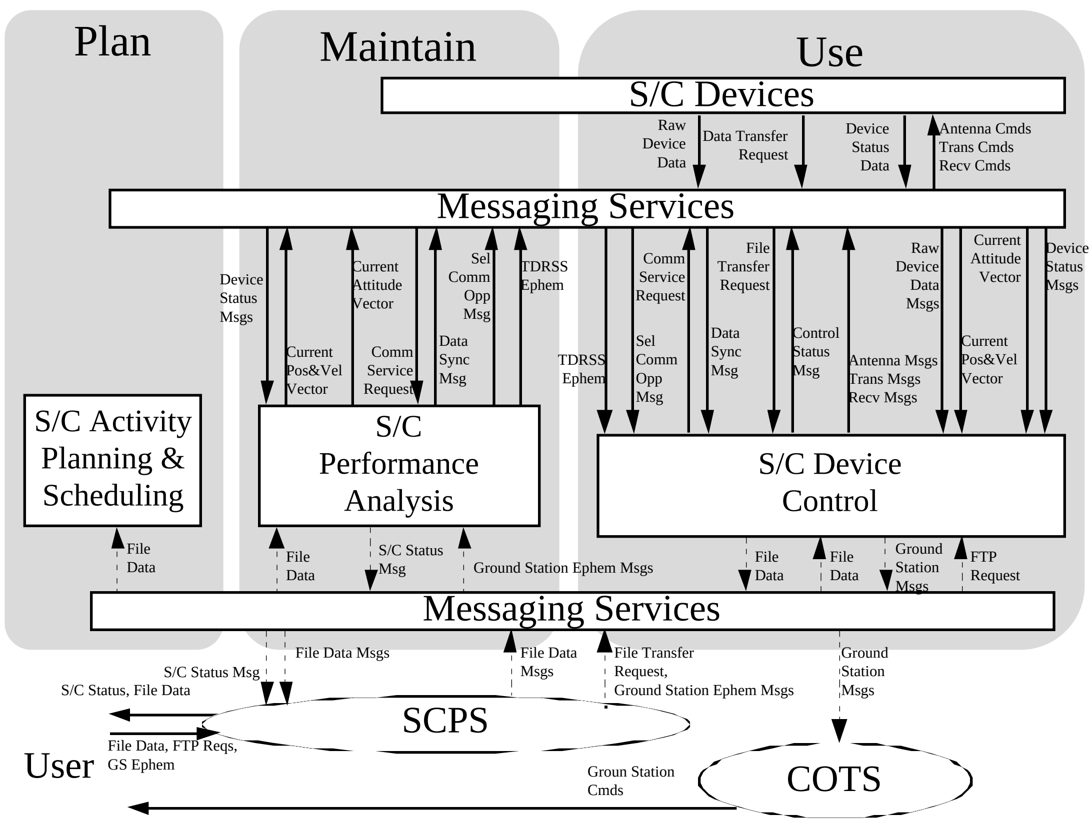

Figure 5-11 SuperMOCA Application of Data Handling Interfaces on board the Spacecraft

Refer to Figure 5-3 for the following discussion. This figure is a depiction of the 10 different types of interfaces found in SuperMOCA compliant implementations. This figure will be used to identify the types of interfaces found in each functional area. This information will be used to identify what capabilities are needed for the space messaging system, and in turn will be used to write the specifications for the messaging system. Table 5-6 below is a breakdown of the interface types for the Data Handling functional area.

Table 5-6 Data Handling Interfaces by Type

Interface Types →	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
File Data	✓		✓		✓		✓		✓
Ground Station Msgs				✓		✓	✓	✓	✓
Ground Station Msg Requests	✓	✓		✓					
Ground Station Ephem Req					✓				
Ground Station Ephem Data									
FTP Request	✓		✓		✓				
FTP Msg					✓		✓		✓
Comm Service Request					✓				✓
Data Sync Msg					✓				✓
Current Pos/Vel Vector					✓				✓
Device Msgs					✓				✓
Raw Device Data Msgs					✓				✓
TDRSS Ephem					✓				
Selected Comm Opp Msg					✓				
Device Status Reports	Internal								
Device Data	Internal								
Device Cmds	Internal								
Data Transfer Request	Internal								
Current Attitude Vector					✓				
Device Status Msg					✓				✓
Control Status Msg					✓				✓

5.2.2.6 System Executive Function

The System's Executive Function's job is to coordinate the 5 SuperMOCA end-to-end functions (Orbit/Trajectory, Attitude/Pointing, Power, Thermal, and Data Handling) to meet the space mission's requirements. In effect it determines whether a system-wide activity or goal can be done safely and effectively. It determines which of the 5 SuperMOCA functions are required to participate and sends messages (either commands or goals) to the participating functions. The knowledge to accomplish this can either be on-board or can be uplinked by the ground, or both. In this first overall scenario (Section 5.2), the cross-functional set of rules, databases, and algorithms is assumed to reside on-board. In the *Plan, Use, Maintain* scheme, the System Executive for example has the following functionality:

- Plan: Plan and schedule observation activities and supporting tasks.
- Use: Control cross-functional activities.
- Maintain: Maintain the integrity of cross-functional control rules and databases.

The System Executive can be a localized process or it can be distributed among the 5 SuperMOCA end-to-end functions.

Refer to Figure 5-12 for the following discussion. This figure was constructed by taking all the interfaces in the ground-spacecraft functional allocations for the 5 SuperMOCA functions (Orbit/Trajectory, Attitude/Pointing, Power, Thermal, and Data Handling) and placing them into one diagram that is meant to show the interfaces to/from the System Executive. The System Executive has the knowledge to determine which interfaces go to which of the 5 SuperMOCA functions on the uplink side. It also has the knowledge to determine which ground subsystem is the recipient of each interface on the downlink side. So for example, the System Executive "knows" that the interface labeled *Desired Attitude "Goal"* coming from the ground is passed on to the Attitude/Pointing Function.

Once a message or file is received by the System Executive, it determines if it needs to be involved in the request. The System Executive may just pass on the message to the appropriate SuperMOCA function, or it may need to apply the appropriate rules or algorithms to the message in order to compute all the necessary conditions required to carry out the request. This computation might be done procedurally, algorithmically, or it might be decision based. Below is an explanation of what is meant by the above three methods of computation.

- *Procedurally* means that the System Executive takes the message and applies a procedure to the contents of the message to generate a list of low-level messages to on-board applications. In current NASA space mission parlance, this is similar to a block call that is simply expanded into a set of time tagged commands.
- *Algorithmically* means that the System Executive takes the message and applies an algorithm to the contents of the message to compute a list of low-level messages to on-board applications based *on the contents of the message* or pre-defined parameters contained in the message. In current NASA space mission parlance, this is similar to a parameterized block call that is simply expanded into a set of time tagged commands based on the values of the block parameters.
- *Decision based* means that the System Executive applies knowledge base rules to the contents of the message to compute a list of low-level messages to on-board applications. These rules may use the contents of the message or parameters thereof, and/or may consult current spacecraft states to perform

the calculations that generate the low-level messages. In other words, the set of low-level messages may be a function of the current spacecraft state.

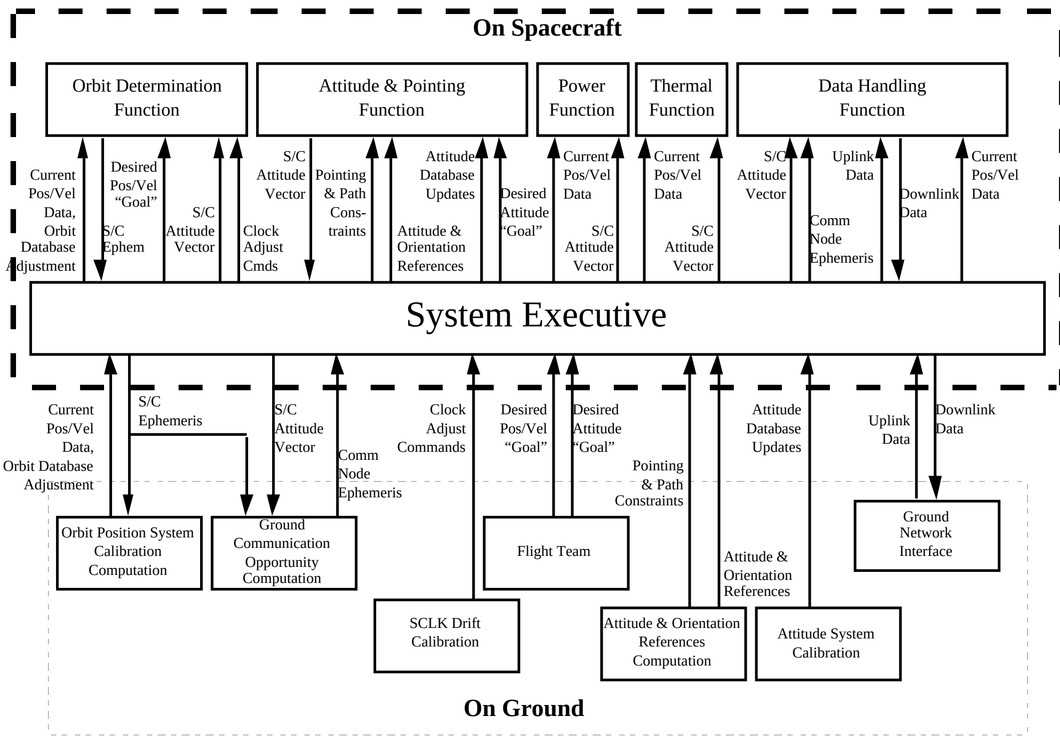

Figure 5-12 Functional Allocation between Space and Ground for the System Executive Function

In the case of an Orbit Modification Message, the System Executive would apply a decision based rule that makes use of several spacecraft states: center-of-mass, current spacecraft attitude, thruster device state, and so on. Since a maneuver is a system-wide activity (more than one SuperMOCA function is involved) the System Executive operates on the incoming message, applies the appropriate rules to come up with a set of application messages that are intended to perform the maneuver safely.

Refer to Figure 5-13 for the following discussion. This figure is a depiction of Figure 5-12 and how those interfaces fall within the SuperMOCA *Plan*, *Use*, *Maintain* viewpoint. The S/C Devices box has been relabeled S/C Applications because the System Executive doesn't interface directly with devices but with the 5 SuperMOCA functions (Orbit/Trajectory, Attitude/Pointing, Power, Thermal, and Data Handling) and the ground.

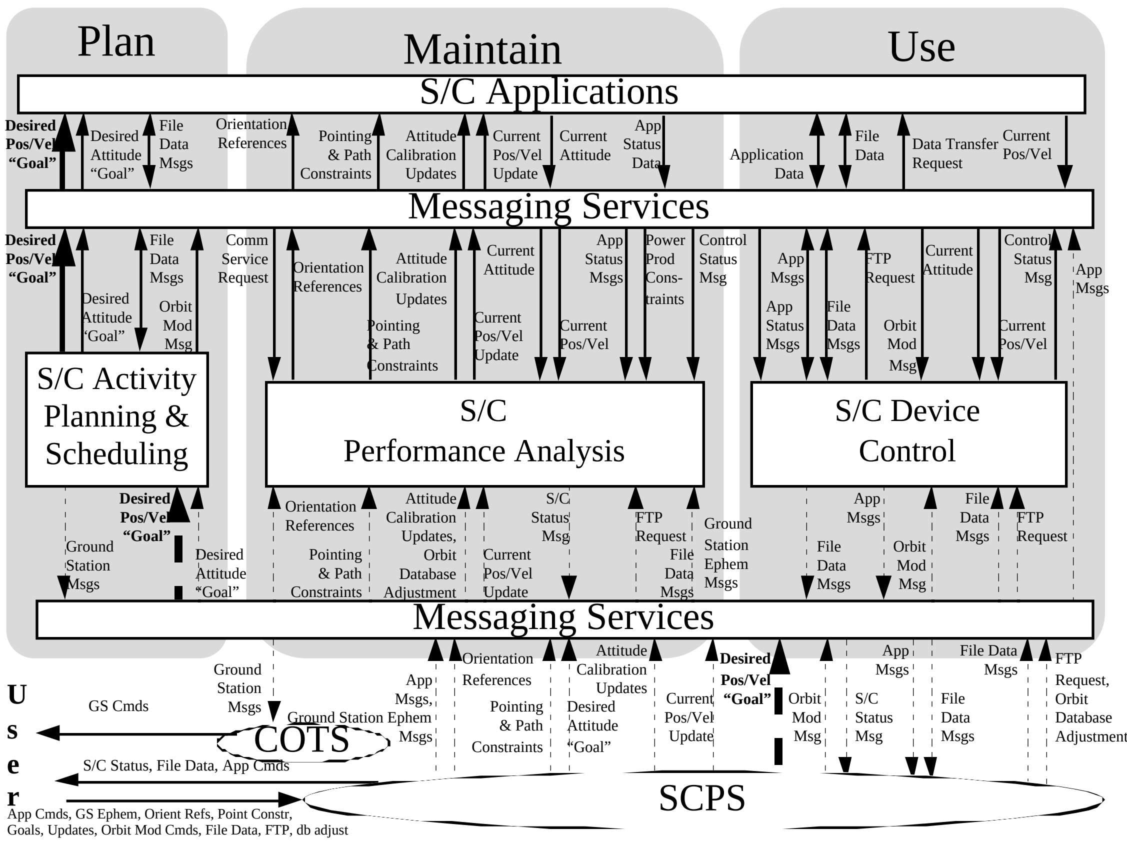

Figure 5-13 SuperMOCA Application of System Executive Interfaces on board the Spacecraft

The System Executive whether a standalone application or a distributed one is tasked with coordinating the 5 SuperMOCA functions. It lies between these functions and the ground. Based on the data that is uplinked from the ground, it determines whether or not to operate on the data itself, pass the data undisturbed to one of the on-board functions, or operate on the data and pass the resultant data to one or more of the SuperMOCA functions. For example in the figure there is an interface labeled *Desired Pos/Vel "Goal"* (the bold arrows in the figure). The System Executive upon receipt of this message can take several courses of actions:

1. The System Executive can pass on the complete message to the Orbit Determination function to take complete control of the maneuver and coordinate with the Attitude/Pointing function.
2. The System Executive can operate on the incoming message passing one portion to the Orbit Determination function (maneuver request portion) and another portion to the Attitude/Pointing function (attitude change portion). With either the Orbit Determination function or the System Executive function signaling the Attitude/Pointing function when the attitude change should occur.

3. The System Executive itself can operate on the message and signal both of the above functions when the activities should commence. The System Executive can hold the maneuver/orientation data until needed by the above functions or it can pass the data to the functions to store until needed.

The choice of options is a project based one that is dependent on overall mission philosophy and spacecraft capabilities.

All the interfaces could not be shown as it would make the figure unreadable. The important point here is the functionality of the System Executive Function. However a complete table of interfaces by type is shown below in Table 5-7.

Table 5-7 System Executive Interfaces by Type

Interface Types →	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Desired Pos/Vel “Goal”					✓		✓		
Desired Pos/Vel “Goal” Req	✓		✓		✓				
Orbit Mod Msg					✓		✓		
Orbit Mod Msg Request	✓		✓		✓				
Orbit Database Adjustment Req					✓				
Orbit Database Adjustment									
Application Msgs					✓		✓		✓
Application Msg Requests	✓		✓		✓				
App Status Data									✓
Application Data									✓
Current Pos/Vel Data Update					✓		✓		✓
Current Pos/Vel Data Update Req	✓		✓						
App Status Msg					✓				
Control Status Msg									✓
Desired Attitude “Goal”					✓		✓		
Desired Attitude “Goal” Req	✓		✓		✓				
Attitude Calibration Updates					✓		✓		
Attitude Calibration Updates Req	✓		✓		✓				
Pointing/Path Constraints					✓		✓		
Pointing/Path Constraints Req	✓		✓		✓				
Orientation References					✓		✓		
Orientation References Req	✓		✓		✓				
Attitude Mod Msg					✓				

Interface Types →	A	C	D	E	F	G	H	I	J
Device Msgs					✓		✓		✓
Device Msg Requests	✓		✓		✓				
Device Status Reports	Internal								
Device Cmds	Internal								
Current Pos/Vel Vector					✓				
Current Attitude Vector					✓				
Desired Attitude Request					✓				
Device Status Msg									✓
Desired Charge Cycle					✓				
Power Production Constraints					✓				
File Data Messages	✓		✓		✓		✓		✓
File Data	✓		✓		✓		✓		✓
Ground Station Msgs				✓		✓	✓	✓	✓
Ground Stations Msg Req	✓	✓		✓					
Ground Station Ephem Req					✓				
Ground Station Ephem Data									
FTP Request Msg					✓		✓		✓
FTP Request	✓		✓		✓				
Comm Service Request					✓				✓
Data Sync Msg					✓				✓
Raw Device Data Msgs					✓				✓
TDRSS Ephem					✓				
Selected Comm Opp Msg					✓				
Device Data	Internal								
Data Transfer Request	Internal								

5.2.3 END TO END SCENARIO OF A SUPERMOCA APPLICATION WITHIN THIS SCENARIO

This scenario depicts the ground commanding the spacecraft to take a picture of some target, compress the data, store it in a file, and transfer the file to the ground. The virtual devices will be:

- a Camera
- an Attitude/Pointing subsystem (AACS)
- a System Executive
- a Ground Terminal
- an Operations Control Center

Assumptions:

- A messaging system that is based on MMS[4] is used for passing messages between virtual devices.
- All virtual devices know where all the other virtual devices are by way of address tables in each virtual device's memory.
- The devices model more the peer/peer communications model than the client/server model in that devices can act the part of a server or a client at any point in time.
- Each device is capable of announcing itself and its capabilities, for example:
  - list of local read/write variables
    - symbolic names and data types
  - list of local files
  - data types it understands
  - services it understands, for example:
    - write
    - read
    - status
    - unsolicited status
    - semaphores
    - event notification
    - file operations
    - information reports
  - device class
  - model number
  - SMS version
- The protocol for the Space Messaging System that is assumed here is that a client initiates a connection to a server which responds with an identification message. So for any ”conversation” there is a client and a server.
- The Ground Terminal upon receipt of an “acquire spacecraft” message can know the position of the spacecraft and the path it follows in the sky either by information at the station or by means of data transfers from a project file server.
- The communications link is achieved when the spacecraft is in *listen* mode. This mode could be continuous or it could be pre-planned on-board the spacecraft such that the ground knows when to attempt an *initiate*.
- All virtual devices on-board are on constant *listen* mode.
- All virtual devices have channels for multiple *listen*s and multiple channels for outgoing messages.

[4] Manufacturing Message Specification

- File naming conventions exist on-board the spacecraft and on the ground such that the ground knows by examining the filename where the file came from and what the contents are.
- The camera on board the spacecraft is attached to the bus such that the spacecraft's attitude may need to change in order to point the camera to a target.

Scenario

- Acquisition of the Communications Link
  1. The Operations Center initiates a connection with the Ground Terminal.
  2. The Ground Terminal responds positively to the *initiate* message.
  3. The Ground Terminal announces itself and its capabilities to the Operations Center.
  4. The Operations Center sends an "acquire" directive to the Ground Terminal to acquire the spacecraft for communications from time A to time B.
  5. The Ground Terminal responds positively to the "acquire" directive and gathers the information necessary to track and communicate with the spacecraft.
  6. The Ground Terminal creates a *semaphore* and maps the communications link to it such that if the link should break, the Ground Terminal sends a message to the Operations Center to that effect.
  7. The Ground Terminal acquires the spacecraft.
  8. The Ground Terminal initiates a connection with the spacecraft's System Executive.
  9. The System Executive responds positively to the *initiate* message.
  10. The System Executive announces itself and its capabilities to the Ground Terminal.
  11. The Ground Terminal sends a message to the Operations Center that the link with the spacecraft is open for communications.
- Initiation of a connection with the spacecraft by the Operations Center
  12. The Operations Center initiates a connection with the spacecraft's System Executive.
  13. The System Executive responds positively to the *initiate* message.
  14. The System Executive announces itself and its capabilities to the Operations Center.
  15. The Operations Center sends a message to the System Executive commanding the spacecraft to take a picture of target T with an exposure of duration E and filter F utilizing compression algorithm C.
  16. The System Executive upon receipt of the message, parses the message to know where to send the message, and determines if there are spacecraft attitude changes required.
- Initiation of connections on-board the spacecraft
  17. The System Executive initiates a connection with the spacecraft's Camera.

18. The Camera responds positively to the *initiate* message.
19. The Camera announces itself and its capabilities to the System Executive.
20. The System Executive sends a message to the Camera commanding it to take a picture of a target T with an exposure of duration E and filter F utilizing compression algorithm C when it receives a notification from the AACS that the attitude change has been completed.
21. The System Executive sends a message to the Camera to inform it when the shutter closes.
22. The Camera creates an *event notification* such that when the activity is complete (in this case the shutter is closed), the event enrollees (only the System Executive in this case) are notified upon the occurrence of the event.
23. The System Executive initiates a connection with the Attitude/Pointing Subsystem.
24. The Attitude/Pointing Subsystem responds positively to the initiate message.
25. The Attitude/Pointing Subsystem announces itself and its capabilities to the System Executive.
26. The Camera initiates a connection with the Attitude/Pointing Subsystem.
27. The Attitude/Pointing Subsystem responds positively to the *initiate* message.
28. The Attitude/Pointing Subsystem announces itself and its capabilities to the Camera.

- Preparation by on-board subsystems to execute the Operations Center message

29. The System Executive sends a message to the Attitude/Pointing Subsystem instructing it to point the Camera at target T.
30. The Camera sends a message to the Attitude/Pointing Subsystem to inform it when the attitude change is completed.
31. The Attitude/Pointing Subsystem creates an *event notification* such that when the pointing is complete, the event enrollees (only the Camera in this case) are notified upon the occurrence of the event.
32. The Attitude/Pointing Subsystem sends a message to the Camera to inform it when the shutter is closed.
33. The Camera creates an *event notification* such that when the shutter is closed, the event enrollees (only the Attitude/Pointing Subsystem in this case) are notified upon the occurrence of the event.

- Execution of the Operations Center message

34. The Attitude/Pointing Subsystem computes the required attitude change and performs the requested attitude change.
35. The Attitude/Pointing Subsystem sends an *event_notice* that the turn has been completed to all those interested in that event.
36. The Camera upon receipt of the *event_notice* from the Attitude/Pointing Subsystem turns filter wheel to filter F, exposes the CCD for a duration of time E, and then closes the shutter.

37. The Camera sends an *event_notice* that the shutter has been closed to all those interested in that event (the Attitude/Pointing Subsystem and the System Executive).
38. The Camera reads the CCD and applies compression algorithm C to the raw data and stores it in a local buffer.
39. The Camera sends an *event_notice* that the activity is completed to all those interested in that event (the System Executive).

- Transmission of the image file by the spacecraft to the ground

40. The Camera sends the image file to the System Executive using SCPS-FTP.
41. The System Executive upon receipt of the image data, stores it in mass storage (solid state recorder for example).
42. The System Executive sends the image file to the Operations Center using SCPS-FTP.

- Termination of connections on-board the spacecraft

43. The Camera concludes the connection to the Attitude/Pointing Subsystem.
44. The Attitude/Pointing Subsystem responds positively to the *conclude* message.
45. The System Executive concludes the connection to the Camera.
46. The Camera responds positively to the *conclude* message.
47. The System Executive concludes the connection to the AACS.
48. The AACS responds positively to the conclude message.

- Termination of connections by the ground

49. Upon receipt of the image file, the Operations Center concludes the connection to the System Executive.
50. The System Executive responds positively to the *conclude* message.
51. The Operations Center concludes the connection to the Ground Terminal.
52. The Ground Terminal responds positively to the *conclude* message.
53. At time B, the Ground Terminal concludes the connection to the System Executive.
54. The System Executive responds positively to the *conclude* message.

5.2.4 SUMMARY OF SUPERMOCA VIEW OF SCENARIO 1

Refer to Figure 5-3 for the following discussion. Table 5-8 below summarizes the 248 interface types that are found in this spacecraft scenario from the SuperMOCA perspective. It shows that most of the interfaces are type F (interfaces to/from onboard Decision Support Logic) and type J (to/from onboard virtual devices). This is as expected since the problem that SuperMOCA addresses in this I&T scenario is for the most part the monitor and control of onboard devices.

Since the two most common types of interfaces are F and J, it can be inferred that the **SMS↔ DSL** interface and the **SMS ↔Virtual Device** interface are both very important to the success of SuperMOCA. This also means that issues like performance, functionality, and operability become critical at these junctures. Specifications for these two interface types (F and J) must be given close attention and become at least for this scenario crucial to the success of SuperMOCA.

Table 5-8 Summary of Interface Types for Scenario 1

	A	C	D	E	F	G	H	I	J	Internal
Number of Interfaces	**33**	**2**	**30**	**4**	**84**	**2**	**32**	**2**	**43**	**16**
% of Total Interfaces	**13%**	**1%**	**12%**	**2%**	**34%**	**1%**	**13%**	**1%**	**17%**	**6%**

5.3 SCENARIO 2 - LOW LEVEL OF SPACECRAFT AUTONOMY

5.3.1 MISSION PHASE VIEWPOINT

See Section 5.2.1.

5.3.2 SUPERMOCA FUNCTIONAL AREA VIEWPOINT

The intent of this section is to provide a description of how a space mission that adheres to SuperMOCA could operate each of the functional areas depicted in the SuperMOCA Architecture Document given a low level of autonomy present in the mission.

5.3.2.1 Orbit/Trajectory Function

This section is the same as Section 5.2.2.1 except that this design provides ground control of orbit maneuvers including low earth orbit missions, measurement of spacecraft position, and determination of an accurate time reference.

Refer to Figure 5-14 for the following discussion. This section is the same as Section 5.2.2.1 with the following exceptions. 1) Current velocity and position data is not uplinked to the spacecraft (for LEO missions, a GPS receiver can provide position and velocity data to the ground, see D in figure).

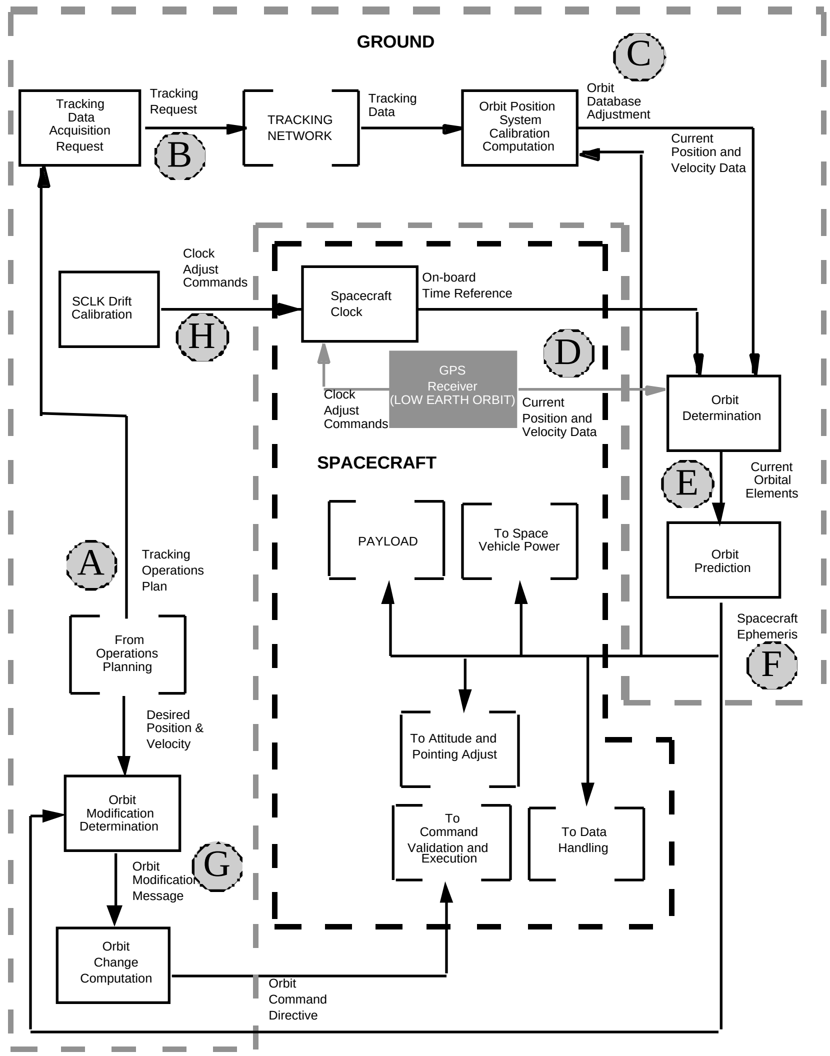

Figure 5-14 Functional Allocation between Space & Ground for the Orbit Determination Function

2) The Orbit Determination function is now found in the ground (see E in figure). 3) The Orbit Modification function (see F in figure) calculates the desired spacecraft ephemeris and the delta-V required, the delta-V direction, and the epoch of the TCM (see G in figure). This data is uplinked to the spacecraft for execution of the maneuver. Usually the ground has a secondary uplink window in which to uplink last-minute modifications the maneuver parameters. 4) Time data updates (as a result of oscillator drift predicts) are supplied by the ground (see H in the figure) or by a GPS receiver on board LEO spacecraft.

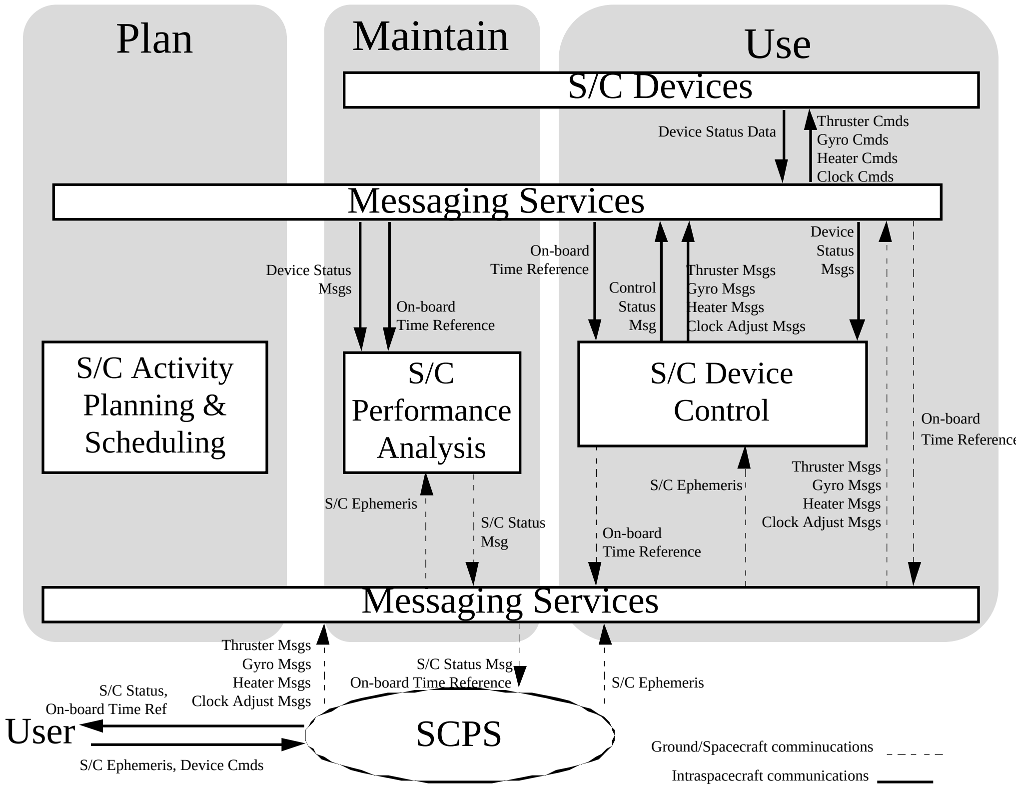

Figure 5-15 SuperMOCA application of Orbit Determination Interfaces on board the Spacecraft

Refer to Figure 5-15 for the following discussion. This figure is an application of the interfaces in Figure 5-14 to the Plan, Use, Maintain SuperMOCA concept on board the Spacecraft. This section is the same as the discussion of Figure 5.2.2-2 with the following exceptions. 1) The ground uplinks via the SCPS protocol necessary information (e.g., spacecraft ephemeris and device commands) as messages to the Spacecraft Performance Analysis and Spacecraft Device Control functions in order for the spacecraft to execute the maneuver at the appropriate time.

2) The Spacecraft Device Control function (***Use*** in the figure) performs the maneuver based on the uplinked maneuver parameters at the scheduled time sending the actual commands to the devices (thrusters, heaters, valves).

Table 5-9 below is a breakdown of the interface types (see Figure 3-5) for the Orbit Determination functional area.

Table 5-9 Orbit Modification Interfaces by Interface Type

Interface Type →	A	C	D	E	F	G	H	I	J
S/C Ephemeris	✓		✓		✓		✓		✓
On Board Time Reference	✓		✓		✓		✓		✓
S/C Status Msg	✓		✓				✓		✓
Device Msg Requests	✓		✓		✓				
Device Msgs					✓		✓		✓
Device Status Reports	**Internal**								
Device Cmds	**Internal**								
Device Status Msg									✓
Control Status Msg									✓

5.3.2.2 Attitude/Pointing Function

Refer to Figure 5-16 for the following discussion. This section is the same as Section 5.2.2.2 with the following exceptions. 1) Consistent with a low level of spacecraft autonomy in this scenario, the design depicted here reflects control of major attitude maneuvers by the ground. 2) The ground either pre-launch or as a result of post-launch analysis, provides the spacecraft with a set of references to use in computation of attitude/orientation vectors - these references could be star catalogues or yaw/pitch/roll deadband limits for example (see A in figure). Pointing and path constraints are used by the ground to determine the proper spacecraft attitude. 3) The ground can determine in several ways if an attitude change maneuver needs to be executed. 4) The ground using pointing and path constraints (developed pre-launch as part of the mission design or as a result of post-launch analysis of spacecraft/instrument performance), spacecraft ephemeris, the current attitude vector supplied by the spacecraft, and the predicted attitude can generate the desired attitude modification parameters, and uplink an attitude maneuver directive to the spacecraft (see D in figure). 5) In the case of routine attitude control (vector addition between the current attitude and the attitude hold vectors) the spacecraft can determine if the error is great enough that an attitude maneuver is necessary (see E in figure).

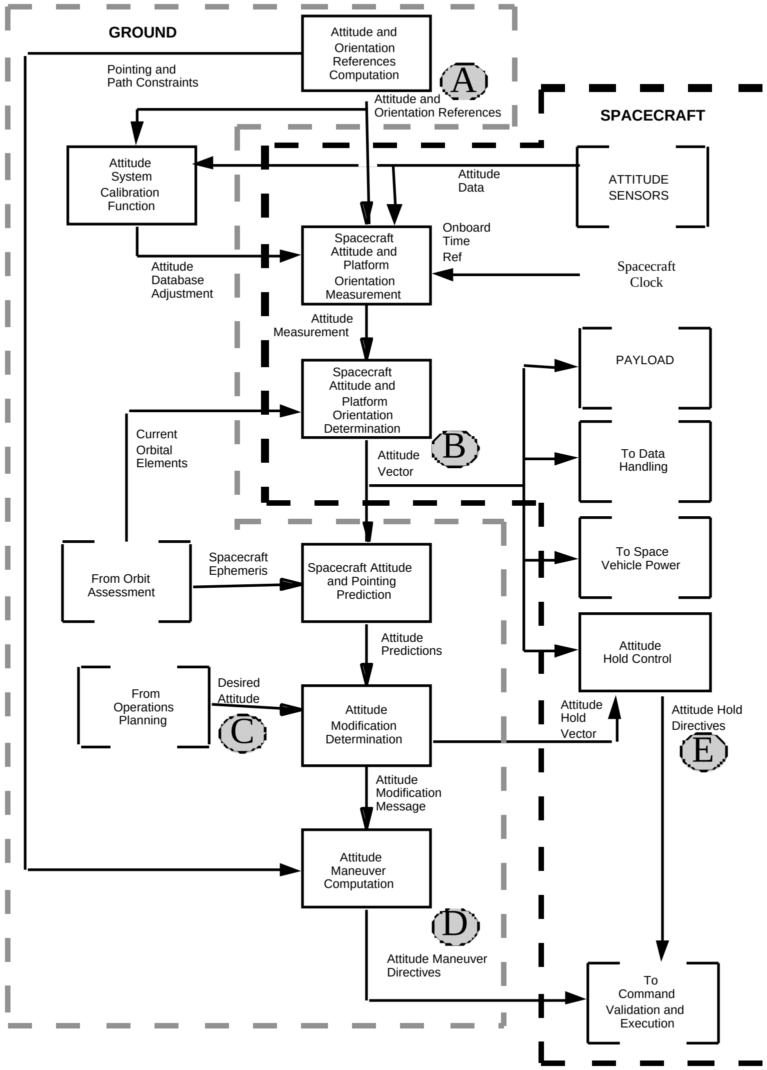

Figure 5-16 Functional Allocation between Space & Ground for the Attitude/Pointing Function

Also the ground can predict the maneuver parameters and compare them to the spacecraft generated parameters as a check against on board algorithms.

Refer to Figure 5-17 for the following discussion. This figure is an application of the interfaces in Figure 5-16 to the Plan, Use, Maintain SuperMOCA concept on board the Spacecraft. This section is the same as the discussion of Figure 5-5 with the following exceptions. 1) The ground uplinks, via the SCPS protocol, necessary information as messages to the S/C Performance Analysis and S/C Device Control functions (attitude reference changes, calibration updates, S/C clock adjustment commands, orbital elements, attitude hold vector, and attitude maneuver directives) for the S/C to maintain routine S/C orientation and to perform major attitude maneuvers.

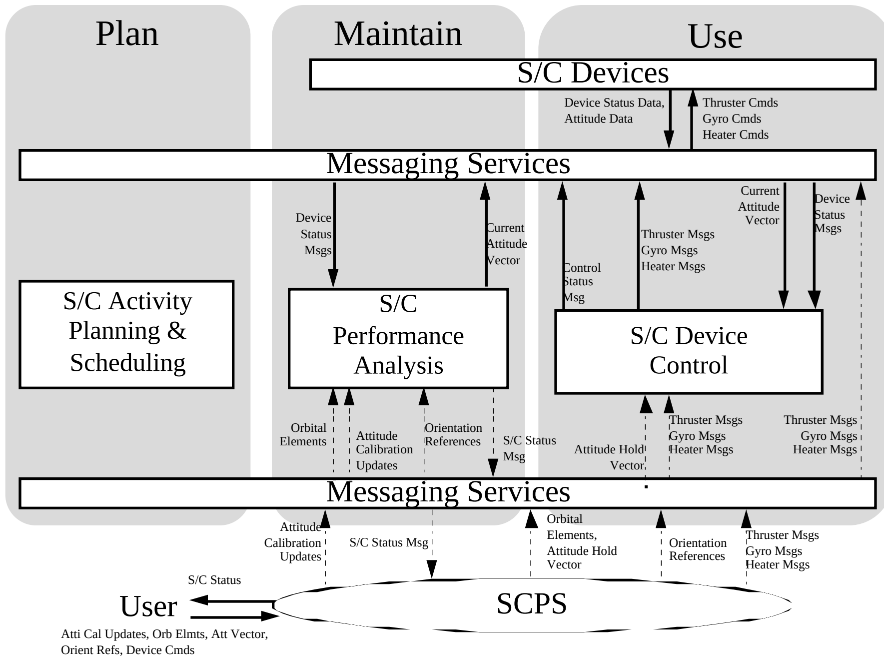

Figure 5-17 SuperMOCA application of Attitude Pointing Interfaces on board the Spacecraft

2) With this information plus other on-board supplied data (e.g., S/C time reference, attitude sensor data, and current S/C states), the S/C Performance Analysis function (***Maintain*** in the figure) determines if an attitude modification maneuver is required to maintain routine attitude control. 3) If so, it sends out a device message here called an Attitude Modification message. This Attitude Modification message is sent to the Device Control function (***Use*** in the figure) which then calculates the epoch, the difference between the actual attitude vector and the desired attitude vector, and finally the attitude change parameters. 4) If the ground determines that a major attitude change is required then the ground sends the Attitude Modification message to the Performance Analysis function or the individual device messages to the spacecraft to the Device Control function.

Table 5-10 is a breakdown of the interface types for the Attitude/Pointing functional area.

Table 5-10 Attitude/Pointing Interfaces by Type

Interface Type ⟶	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Attitude Calibration Updates	✓		✓				✓		✓
Orbital Elements	✓		✓				✓		✓
Attitude Hold Vector	✓		✓				✓		✓

Interface Type →	A	C	D	E	F	G	H	I	J
Orientation Reference Updates	✓		✓				✓		✓
Attitude Mod Msg	✓		✓		✓		✓		✓
Device Msgs	✓		✓		✓		✓		✓
Device Status Reports	**Internal**								
Attitude Data	**Internal**								
Device Cmds	**Internal**								
Current Attitude Vector					✓				✓
Device Status Msg					✓				✓
Control Status Msg					✓				✓

5.3.2.3 Space Vehicle Power Function

See Section 5.2.2.3. This function is the same as for the high level of autonomy scenario.

5.3.2.4 Space Vehicle Thermal Function

See Section 5.2.2.4. This function is the same as for the high level of autonomy scenario.

5.3.2.5 Data Handling Function

Refer to Figure 5-18 for the following discussion. This section is the same as Section 5.2.2.5 with the following exceptions. 1) In this SuperMOCA low spacecraft autonomy scenario, only the normal scheduled communications mode of communication between space and ground is available. Scheduled communications allow the contact to be planned in advance. 2) The data synchronization management function is responsible for determining when communications should be initiated, for example, immediate action when the spacecraft is directed by the flight team to transfer payload data, or when the flight team wants to uplink commands (see As in the figure). 3) The ground data synchronization management function triggers antenna selection and pointing to establish a space-ground link (see C in the figure). 4) For low Earth orbiting vehicles, TDRSS contacts schedule and ephemerides are used by the ground communications opportunity computation to control the transponder modes and transponder on/off times. 5) Using the spacecraft attitude information, the spacecraft ephemeris, and the ephemeris of the TDRSS spacecraft (see H in the figure), this function computes the required pointing angles and pointing commands for the HGA, accounting for obstructions of the antenna views, etc.

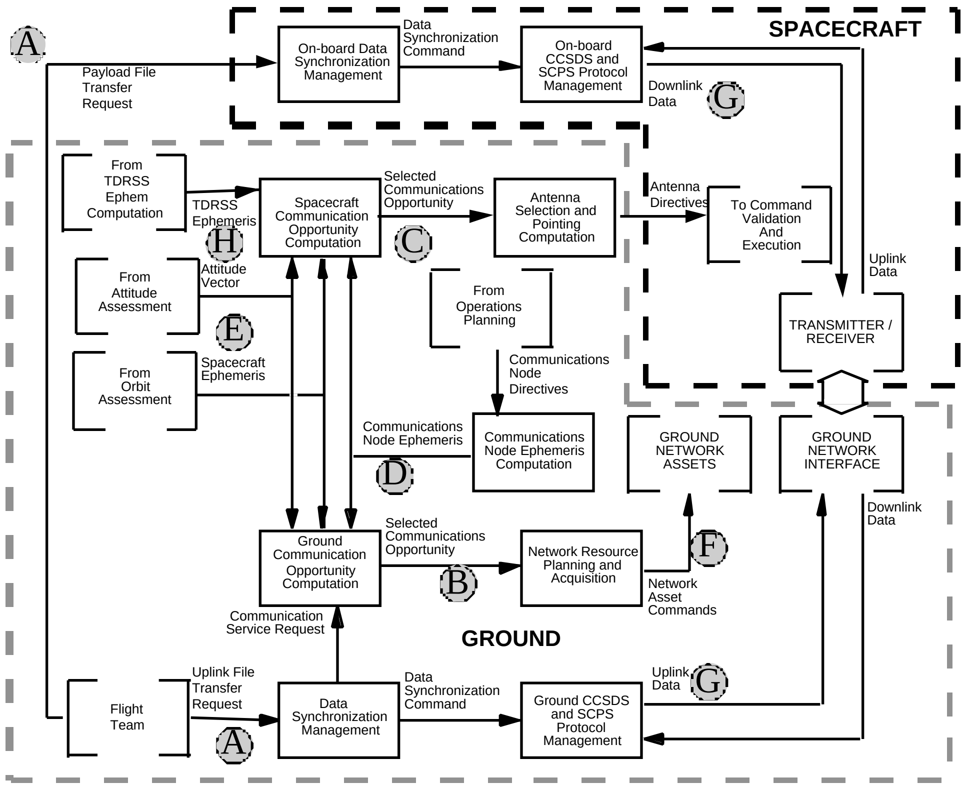

Figure 5-18 Functional Allocation between Space and Ground for the Data Handling Function

Refer to Figure 5-19 for the following discussion. This section is the same as the discussion of Figure 5-11 with the following exceptions. 1) The Device Control function (***Use*** in the figure) receives file transfer request from the ground. 2) The ground generates a Communications Service Request and performs computations that might require changes to the position and attitude of the spacecraft and the position of external communications nodes (TDRSS for low Earth orbiting vehicles for example). 3) Upon receipt of a data transfer request by the ground, Data Synchronization messages are sent to the Device Control for management of the queued data. 4) Other messages that are generated include information regarding the downlink path chosen by the ground.

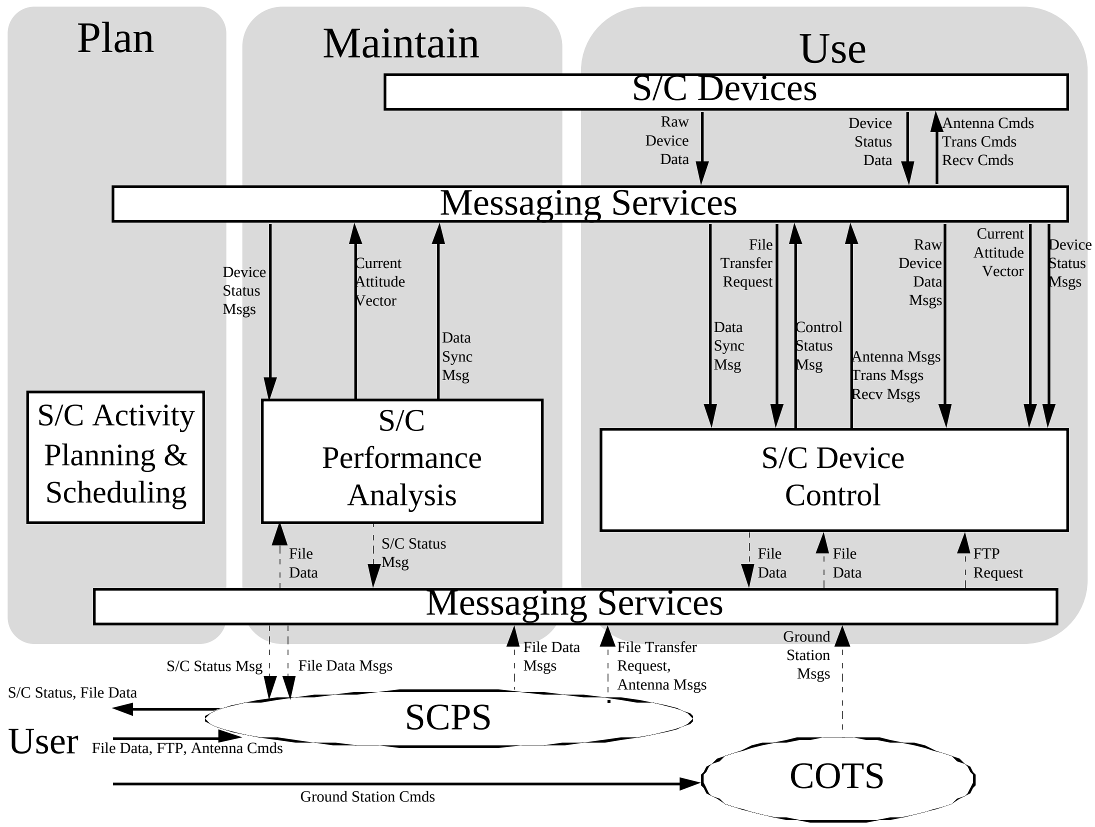

Figure 5-19 SuperMOCA Application of Data Handling Interfaces on board the Spacecraft

Table 5-11 below is a breakdown of the interface types for the Data Handling functional area.

Table 5-11 Data Handling Interfaces by Type

Interface Types →	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
File Data	✓		✓				✓		✓
Ground Station Msgs				✓		✓	✓	✓	✓
Ground Station Msg Requests	✓	✓		✓					
FTP Request	✓		✓		✓				
FTP Msg					✓		✓		✓
Data Sync Msg					✓				✓
Current Pos/Vel Vector					✓				✓
Device Msgs					✓				✓
Raw Device Data Msgs					✓				✓
TDRSS Ephem					✓				

Interface Types →	A	C	D	E	F	G	H	I	J
Device Status Reports	**Internal**								
Device Data	**Internal**								
Device Cmds	**Internal**								
Data Transfer Request	**Internal**								
Current Attitude Vector					✓				
Device Status Msg					✓				✓
Control Status Msg					✓				✓

5.3.2.6 System Executive Function

This section is the same as Section 5.2.2.6 with the following exceptions. 1) In this second overall scenario the cross-functional set of rules, databases, and algorithms is assumed to reside primarily on the ground. Figure 5-20 was constructed as described in Section 5.2.2.6.

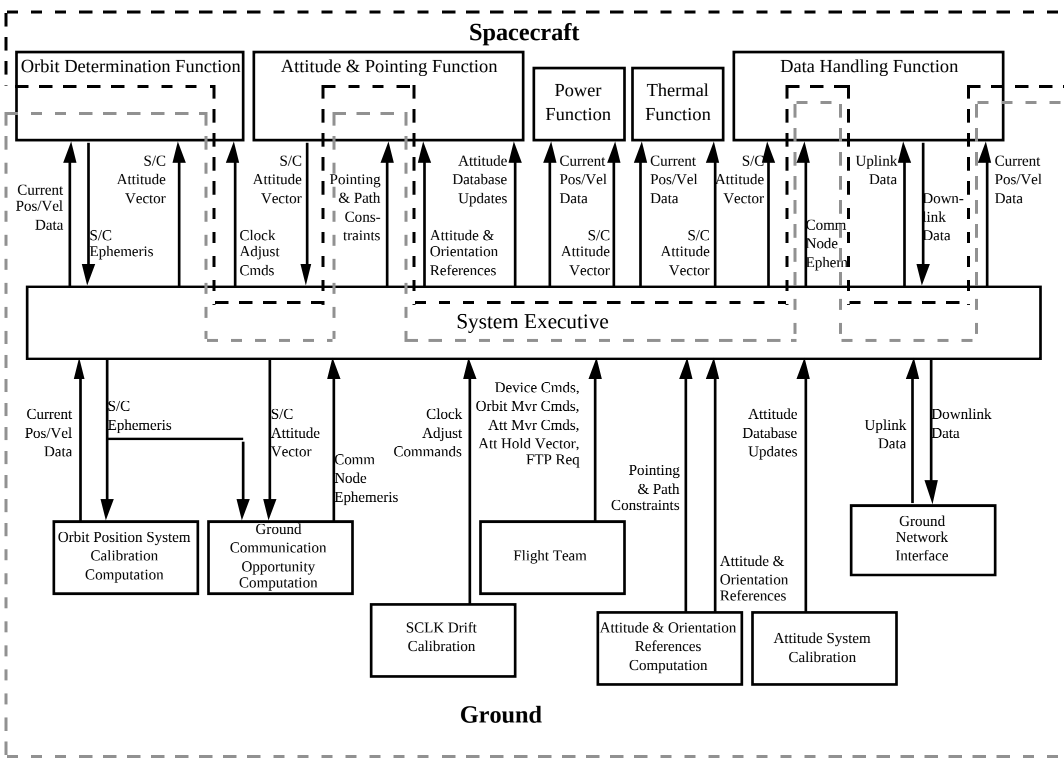

Figure 5-20 Functional Allocation between Space and Ground for the System Executive Function

Refer to Figure 5-21 for the following discussion. This section is the same as the discussion of Figure 5-13 with the following exceptions.

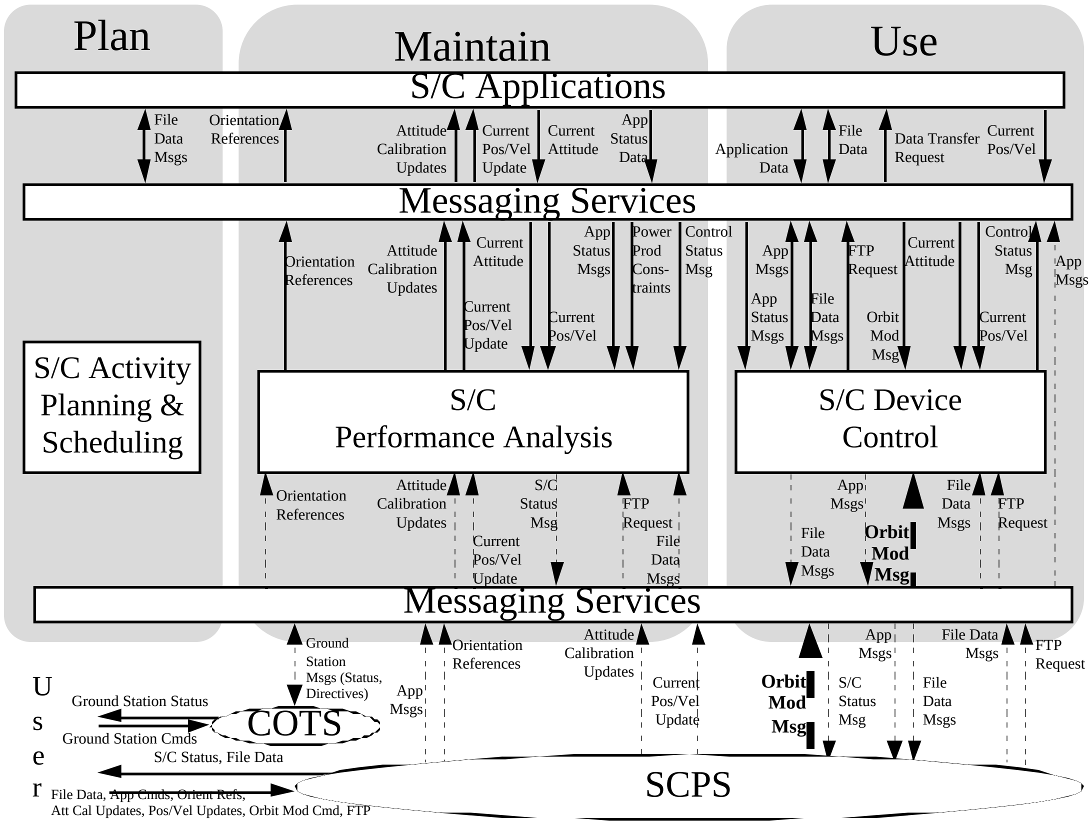

Figure 5-21 SuperMOCA Application of System Executive Interfaces on board the Spacecraft

The example in this discussion is the interface labeled *Orbit Modification Message* (the bold arrows in the figure). The System Executive upon receipt of this message can do one of two things:

1. The System Executive can operate on the incoming message passing one portion to the Orbit Determination function (maneuver request portion) and another portion to the Attitude/Pointing function (attitude change portion). With either the Orbit Determination function or the System Executive function signaling the Attitude/Pointing function when the attitude change should occur.
2. The System Executive itself can operate on the message and signal both of the above functions when the activities should commence. The System Executive can hold the maneuver/orientation data until needed by the above functions or it can pass the data to the functions to store until needed.

A table of interfaces by type is shown below in Table 5-12.

Table 5-12 System Executive Interfaces by Type

Interface Types →	A	C	D	E	F	G	H	I	J
S/C Status Msg	✓		✓				✓		✓
Orbit Mod Msg					✓		✓		
Orbit Mod Msg Request	✓		✓		✓				
Application Msgs					✓		✓		✓
Application Msg Requests	✓		✓		✓				
App Status Data									✓
Application Data									✓
Current Pos/Vel Data Update					✓		✓		✓
Current Pos/Vel Data Update Req	✓		✓						
App Status Msg					✓				
Control Status Msg									✓
Attitude Calibration Updates					✓		✓		
Attitude Calibration Updates Req	✓		✓						
Orientation References					✓		✓		
Orientation References Req	✓		✓						
Attitude Mod Msg					✓				
Device Msgs							✓		✓
Device Msg Requests	✓		✓						
Device Status Reports	Internal								
Device Cmds	Internal								
Current Pos/Vel Vector					✓				
Current Attitude Vector					✓				
Desired Attitude Request					✓				
Device Status Msg									✓
Desired Charge Cycle					✓				
Power Production Constraints					✓				
File Data Messages	✓		✓				✓		✓
File Data	✓		✓				✓		✓
Ground Station Msgs				✓		✓	✓	✓	✓
Ground Stations Msg Req	✓	✓		✓					
FTP Request Msg					✓		✓		✓
FTP Request	✓		✓		✓				
Comm Service Request					✓				✓
Data Sync Msg					✓				✓
Raw Device Data Msgs					✓				✓

Interface Types →	A	C	D	E	F	G	H	I	J
TDRSS Ephem					✓				
Selected Comm Opp Msg					✓				
Device Data	**Internal**								
Data Transfer Request	**Internal**								

5.3.3 END TO END SCENARIO OF A SUPERMOCA APPLICATION WITHIN THIS SCENARIO

This scenario is the same as the one described in Section 5.2.3 with the exceptions noted below in ***bold-italic*** font.

Scenario

- **Acquisition of the Communications Link**

  Same as Section 5.2.3
- **Initiation of a connection with the spacecraft by the Operations Center**
- The Operations Center initiates a connection with the spacecraft's System Executive.
  2. The System Executive responds positively to the *initiate* message.
  3. The System Executive announces itself and its capabilities to the Operations Center.
  4. ***The Operations Center sends a message to the System Executive commanding the spacecraft to go to attitude A at time X, take a picture with an exposure of duration E and filter F utilizing compression algorithm C.***
  5. ***The System Executive upon receipt of the message, parses the message to know where to send the message.***
- **Initiation of connections on-board the spacecraft**
  6. The System Executive initiates a connection with the spacecraft's Camera.
  7. The Camera responds positively to the *initiate* message.
  8. The Camera announces itself and its capabilities to the System Executive.
  9. ***The System Executive sends a message to the Camera commanding it to take a picture with an exposure of duration E and filter F utilizing compression algorithm C when it receives a notification from the AACS that the attitude change has been completed.***
  10. The System Executive sends a message to the Camera to inform it when the shutter closes.
  11. The Camera creates an *event notification* such that when the activity is complete (in this case the shutter is closed), the event enrollees (only the System Executive in this case) are notified upon the occurrence of the event.
  12. The System Executive initiates a connection with the Attitude/Pointing Subsystem.

13. The Attitude/Pointing Subsystem responds positively to the initiate message.
14. The Attitude/Pointing Subsystem announces itself and its capabilities to the System Executive.
15. The Camera initiates a connection with the Attitude/Pointing Subsystem.
16. The Attitude/Pointing Subsystem responds positively to the *initiate* message.
17. The Attitude/Pointing Subsystem announces itself and its capabilities to the Camera.

- **Preparation by on-board subsystems to execute the Operations Center message**

18. ***The System Executive sends a message to the Attitude/Pointing Subsystem instructing it to go to attitude A at time X.***
19. The Camera sends a message to the Attitude/Pointing Subsystem to inform it when the attitude change is completed.
20. The Attitude/Pointing Subsystem creates an *event notification* such that when the pointing is complete, the event enrollees (only the Camera in this case) are notified upon the occurrence of the event.
21. The Attitude/Pointing Subsystem sends a message to the Camera to inform it when the shutter is closed.
22. The Camera creates an *event notification* such that when the shutter is closed, the event enrollees (only the Attitude/Pointing Subsystem in this case) are notified upon the occurrence of the event.

- **Execution of the Operations Center message**

23. ***The Attitude/Pointing Subsystem performs the requested attitude change at time X.***
24. The Attitude/Pointing Subsystem generates an *event_notice* that the turn has been completed to all those interested in that event.
25. The Camera upon receipt of the *event_notice* from the Attitude/Pointing Subsystem turns filter wheel to filter F, exposes the CCD for a duration of time E, and then closes the shutter.
26. The Camera sends an *event_notice* that the shutter has been closed to all those interested in that event (the Attitude/Pointing Subsystem and the System Executive).
27. The Camera reads the CCD and applies compression algorithm C to the raw data and stores it in a local buffer.
28. The Camera sends an *event_notice* that the activity is completed to all those interested in that event (the System Executive).

- **Transmission of the image file by the spacecraft to the ground**

  Same as Section 5.2.3.

- **Termination of connections on-board the spacecraft**

  Same as Section 5.2.3.

- **Termination of connections by the ground**

  Same as Section 5.2.30.

5.3.4 SUMMARY OF SUPERMOCA VIEW OF SCENARIO 2

Refer to Figure 5-3 for the following discussion. Table 5-13 below summarizes the 215 interface types that are found in this spacecraft scenario from the SuperMOCA perspective. It shows that most of the interfaces are type F (interfaces to/from Decision Support Logic onboard) with type J (to/from onboard virtual devices). This is as expected since the problem that SuperMOCA addresses in this I&T scenario is for the most part the monitor and control of onboard devices.

Since the two most common types of interfaces are F and J, it can be inferred that the **SMS ↔ DSL** interface and the **SMS ↔ Virtual Device** interface are both very important to the success of SuperMOCA. This also means that issues like performance, functionality, and operability become critical at these junctures. Specifications for these two interface types (F and J) must be given close attention and become at least for this scenario crucial to the success of SuperMOCA.

Table 5-13 Summary of Interface Types for Scenario 2

	A	C	D	E	F	G	H	I	J	Internal
Number of Interfaces	**28**	**2**	**26**	**4**	**57**	**2**	**28**	**2**	**49**	**17**
% of Total Interfaces	**13%**	**1%**	**12%**	**2%**	**26%**	**1%**	**13%**	**1%**	**23%**	**8%**

5.4 COMPARISON OF SPACECRAFT I&T, LAUNCH OPERATIONS, AND MISSION OPERATIONS SCENARIOS

It may be useful to compare results from the Spacecraft I&T (see Table 3-7), Launch Operations (see Table 4-7 and Table 4-8), and Mission Operations scenarios (see Table 5-8and Table 5-13) to see how these phases of a mission are different in the types and numbers of interfaces used.

The important interfaces in the Spacecraft I&T scenario are:

- **User to Control Interface Language**, and
- **Space Messaging System to onboard virtual device**

The important interfaces in the Launch Operations Scenario are:

- **User to Control Interface Language**,
- **Space Messaging System to onboard virtual device**, and
- **Control Interface Language to Space Messaging System**
- **Space Messaging System to SCPS stack**

The important interfaces in the Mission Operations Scenario are:

- **Space Messaging System to onboard virtual device**, and
- **Space Messaging System to Decision Support Logic**

From these results it can be inferred that the User/Control Interface Language interface is important in the early phases of a mission. The Control Interface Language/Space Messaging System and the Space Messaging System/SCPS interfaces become important in the middle phases of the mission. Finally the Space Messaging System/Decision Support Logic interface becomes important in the later phase of a mission. The interface that is most important is the Space Messaging System/virtual device interface.